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VALORIZATION OF SARGASSUM SEAWEED FOR SUSTAINABLE AGRICULTURE BASED ON COMPOST AND BIOCHAR PRODUCTION AND APPLICATION IN OKRA (ABELMOSCHUS ESCULENTUS (L.) MOENCH) CULTIVATION IN COASTAL GHANA

PHANUEL YAO KLOGO

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BY

PHANUEL YAO KLOGO

Thesis submitted to the Department of Crop Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Crop Science

OCTOBER 2024

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree at this university or elsewhere. Materials previously published are duly referenced in the text.

Candidate's signature……. Date……

Name: Phanuel Yao Klogo

Supervisor's Declaration

We declare that the preparation and presentation of this thesis were supervised per the guidelines for the supervision of the thesis laid down by the University of Cape Coast.

Principal Supervisor's signature……. … Date…….

Name: Prof. Michael O. Adu

Co-Supervisor's signature……..... Date……

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Co-Supervisor's signature……. Date……

Name: Dr Kwadwo Kusi Amoah

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ABSTRACT

The annual beaching of large volumes of *Sargassum* spp. along Ghana's coastline presents both challenges and opportunities for local communities. This study, from 2021-2023, investigated the potential of utilizing *Sargassum* for agricultural purposes, focusing on its conversion to compost and co-composted biochar, with particular emphasis on okra production, a crucial livelihood activity for many coastal residents in Ghana. A survey involving 782 fishermen from major fishing districts in the Western, Central, and Volta regions revealed extensive local knowledge about *Sargassum*'s beaching patterns, physical characteristics and associated socio-economic impacts, including reduced fish catches, income loss, damage to fishing equipment, and health concerns. A parallel survey of 1,021 farmers indicated widespread use of organic manures in crop cultivation, with okra as the most popular vegetable crop. Farmers expressed willingness to adopt and purchase *Sargassum*-based compost, recognizing its potential benefits. IBM- SPSS was used to analyse data. Four compost formulations with varying proportions of *Sargassum* were developed and analysed. Significant differences (P = 0.01) in pH, electrical conductivity (EC), ammonium-nitrogen (NH_4^+-N), nitrate-nitrogen (NO_3^--N), total carbon, and nitrogen were detected throughout the mesophilic, thermophilic, and cooling phases of the composting process, in addition to the mature compost. The pH of the composts ranged from 6.5 to 7.9, while available P content varied between 992.0 mg/kg and 1,764.0 mg/kg. ANOVA was done using GenStat. Incubation experiments assessed the mineralization dynamics of NPK in the different *Sargassum* composts. Results showed significant variations (P = 0.01) in pH (7.0-7.5), EC (24.7-149.2 µS cm-^{1}), NO_3^--N (0.29-5.58 µg g^{-1}), P (0.90-11.00 µg g^{-1}), and K (0.38-0.44 cmol kg^{-1}). ANOVA was done using GenStat. Experiments conducted in pots with the application of *Sargassum* compost indicated significant (P=0.01) improvements in growth and yield of okra. ANOVA was done using GenStat. Analysis of variance using GenStat of soil after harvest showed significant increases in pH, electrical conductivity (EC), organic carbon, total nitrogen, available phosphorus, exchangeable acidity (Al^{3+} + H^+), and effective cation exchange capacity (ECEC). A strong positive correlation was observed between pH and all tested parameters, with pH values ranging from 6.2 to 7.9. Compost-amended soils consistently outperformed those treated with inorganic fertilizers across all measured parameters. This study demonstrated the feasibility and benefits of repurposing *Sargassum* seaweed into high-quality compost for agricultural use in coastal Ghana. The study examined the environmental issues associated with the accumulation of *Sargassum* and proposed a sustainable approach to soil fertility improvement and increase in crop yields, with a specific focus on okra farming. The positive reception from local farmers and the superior performance of *Sargassum*-based composts compared to inorganic fertilizers suggest a promising pathway for sustainable agricultural practices in coastal communities. These findings have significant implications for waste management, coastal livelihoods, and food security, potentially serving as a model for other regions facing similar *Sargassum* influxes.

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KEY WORDS

Compost mineralisation

Cooling phase

Mesophilic phase

Okra

Sargassum compost

Thermophilic phase

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DEDICATION

To my Daddy, Edward Yao Klogo; Mum, Margaretha Yawa Adzim; my wife, Comfort Zulaihatu Achulo and my children, Nutifafa Grace Klogo and Woedem Wisdom Klogo

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LIST OF ACRONYMS

ANSES	French Agency for Food, Environmental and Occupational Health and Safety
CEC	Cation Exchange Capacity
CEP	Caribbean Environment Programme
CO_2	Carbon IV Oxide
COSCA	Collaborative Analysis of Cassava Africa
CRFM	Caribbean Regional Fisheries Mechanisms
ECEC	Effective Cation Exchange Capacity
ECHO	Enforcement and Compliance History Online
EFJ	European Federation of Journalists
DAP	Diammonium Phosphate
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FYM	Farm Yard Manure
HSD	Tukey's Honestly Significant Difference
IFA	Independent Financial Advisors
IFDC	International Fertilizer Development Centre
IICA	Inter-American Institute for Cooperation on Agriculture
ITCZ	Inter Tropical Convergence Zone
JICA	Japan International Cooperation Agency
LSD	Fisher's Protected Least Significant Difference

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MoFA	Ministry of Food and Agriculture
MoP	Muriate of Potash
NARP	National Agricultural Research Programme
NH_4^+-N	Ammonium Nitrogen
NOAA	National Oceanic and Atmospheric Administration
NO_3^--N	Nitrate Nitrogen
OICI	Opportunity Industrialization Centre International
Ppm	Part per million
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SPAD	Soil Plant Analysis Development
TSP	Tripple Super Phosphate
UNEP	United Nations Environment Programme
WAP	Weeks After Planting

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CHAPTER ONE

INTRODUCTION

Background Information

The most popular annual fruit vegetable that is grown throughout tropical and subtropical regions of Asia and Africa is okra (*Abelmoschus esculentus* (L.) Moench). It is widely grown in India, Philippines, Thailand, Brazil and West Africa (ECHO, 2003; Patil *et al*., 2015). Okra is mostly a self-pollinating crop, which belong to Malvaceae family (Oppong-Sekyere *et al.*, 2011). The value of okra is the green seedpods (Adewole & Ilesanmi, 2011). According to Norman (1992), the immature seedpods contain vitamins A, B, and C. The global production of okra is estimated at 9.96 million tons with India being the largest producer (6.18 million tons) followed by Nigeria (1.82 million tons) (FAOSTAT, 2020). Approximately, 75% of Africa's total okra production is produced in Central and West Africa, where average production amounted to 2.5 t/ha together with East Africa (6.2 t/ha) and North Africa (8.8 t/ha) (FAOSTAT, 2006). Okra is mostly a widely grown tropical vegetable (Babatunde, Omotesho & Sholotan, 2007) and it is grown as either a sole crop or as an intercrop. In Ghana, it is grown mostly in the Bono, Northern, Savanna, Upper East, Upper West, Volta, Greater Accra, and Central Regions (NARP, 1993). Ghana produced 50000, 63860 and 66458 tons of okra in 2010, 2013, and 2017, respectively (FAOSTAT, 2017).

The majority of smallholder farming methods in Ghana are sustainable and do not produce the yields that are anticipated (MoFA 2015 & 2019). Due to improper farming practices, the majority of Ghana's soils have low nutrient levels by nature (Buri & Issaka, 2019). Ghana's soils are deficient in plant nutrients, especially in the northern region where the Sudan and Guinea Savannah agroecological zones are primarily found (Debpuur *et al.*, 2021). The primary causes of the reduction in soil fertility include

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nutrient mining or continuous cropping, leading to soil erosion and nutrient leaching. The soil of Ghana must be managed in order to increase their intrinsic fertility, as the majority of them have low fertility (Benneh, Agyepong & Allotey, 1990). Due to population growth and other external pressures, soil fertility management techniques like long-term land fallowing and crop rotation are gradually being phased out (Agegnehu & Amede, 2017). Investigating sources of organic fertilizer may help address the nutrient shortage and decreasing soil productivity, resulting in sustainable agriculture (Gyamfi, Loos & Anthofer, 2001).

Until now, decreased soil fertility was restored by the use of inorganic (mineral) fertilizers by farmers. However, because most farmers cannot purchase such mineral fertilizers, Ghana uses very little inorganic fertilizer. Farmers always do not use it at the suggested rates (FAO, 2005). In the meantime, the increased use of inorganic fertilizers in agriculture leads to a growing number of health and permanent environmental issues, such as water body contamination, acidification, low yield, short shelf life, soils, and food poisoning or bitterness (Yanar *et al*., 2011). Inorganic nitrogen (N) and mineral phosphorus (P) fertilizers are the main sources of pollution in the environment. Applying mineral N to soils causes an increase in nitrate ions (NO_3^-), which is then found in the edible portions of the plants that are grown there (Randy, 2011a). Large concentrations of the heavy metal cadmium (Cd^{2+}) are found in phosphate fertilizers, which is linked to both harmful health effects for humans and decreased agricultural output (McLaughlin *et al.*, 2000). Thus, the intensive use of mineral phosphorus fertilizers leads to contamination by Cd^{2+} that is easily absorbed by the roots of plants, and this is frequently transported to other parts of these plants (Semida *et al*., 2015). To minimize or eliminate these negative effects of inorganic fertilizers, organic agriculture has been developed (Chowdhury, 2004).

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Because of the fruit's lower chemical residues and superior flavour, vegetables cultivated with organic manure are becoming more and more popular (Asimenu MoFA Director, Western Region, Personal communication, 2023). Additionally, organic manures supply nutrients slowly for plant growth and control the population of plant pests. Moreover, their incorporation into the soil and the mineralization that follows increases accumulation of organic matter in the soil, enhance microbial activity and the capacity for cation and anion exchange. In the end, they boost crop productivity and produce quality crops (Singh & Siateramaiah, 1970; Hoitink & Boehn, 1999; Bulluck *et al.*, 2002; Heeb *et al.*, 2005; Heeb *et al.*, 2006; Liu, Grumpertz *et al.*, 2007; Toufack, *et al.*, 2009).

Composts are known to enhance soil structure, release nutrients gradually and eventually promote the establishment of beneficial soil bacteria, all of which contribute to the health of the soil (Neeson, 2004). Additionally, when soils are poor in organic matter and low in mineralization, compost is used as a source of nutrients in normal or saline conditions (Okusami *et al.*,1997; Ojo *et al.*, 2014; Smith *et al.*, 2015). Combining organic manure with inorganic fertilizer leads to improved crop productivity, soil fertility, sustainability and balanced plant nutrition (Randy 2011a; Moyin-Jesu, 2015; Riaz *et al.*, 2015; Semida *et al.*, 2015; Dotaninja *et al.*, 2016; Kalaivanan & Hatab, 2016; Kumar & Chopra., 2016). In addition, farm yard manure and green manures also positively affect soil fertility (Kumar *et al.*, 2014; Suja & Sreekumar, 2014). Some vegetables, including garden eggs, have been shown to yield significantly more when organic manure is applied as opposed to inorganic manure (Ulah *et al.*, 2008; Annoop & Chaubau, 2009).

The use of biochar increases water-holding capacity and carbon sequestration, which could lower greenhouse gas emissions (Bakewell-Stone, 2011; Verheijen *et al.*,

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2010; Lehmann & Rondon, 2006; Downie, 2009). Biochar recharges and make available soil nutrients for plant use. This is due to Ghanaian soils having low amounts of soil nutrient and the majority of vital plant macronutrients like phosphorus and nitrogen (Dwomo & Dedzoe, 2010). Accordingly, using biochar lessens the need for fertilizer and slows down the degradation of the ecosystem (Yeboah *et al.*, 2009). Biochar lasts longer in soils than inorganic fertilizers and is less prone to biological deterioration (Mutezo, 2013). Furthermore, it may draw fungi and microbes that enhance soil texture and structure (Verheijen *et al.*, 2010).

More than 300 species of *Sargassum*, a genus of brown seaweed, domicile in both temperate and tropical regions of the world (UNEP-CEP, 2021). While other seaweeds reproduce and start their lives on the ocean floor (benthic phase), the *Sargassum* spp. of interest is a special kind that is classified as halopelagic since it grows vegetatively on the high seas in addition to being free-floating (Laffoley *et al*., 2011). On Ghana's western coast, a sighting of a *Sargassum* was first reported in 2009 (Addico & deGraft Johnson, 2016), even though between 2011 and 2012, the first significant influx was noted (Ackah-Baidoo, 2013; Fidai *et al*., 2020; Marsh *et al*., 2021). There has been an annual increase in *Sargassum* density since that initial report. In the past, the management of crop residue, green manure, animal manures and leguminous cover crops have been the focus of research utilizing organic materials for crop productivity (Toufack *et al*., 2009). However, the recent influxes of *Sargassum* spp. (brown algae species) onto the coastline of the West African sub-region (Oyesiku & Egunyomi, 2014; Addico & deGraft Johnson, 2016) present an opportunity for the production of co-composts (that is preparing biochar and mixing it with other feedstock to produce compost) for the cultivation of okra. Composting the *Sargassum* spp may not only provide a cheap source of manure for farming, but it may also provide a

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complementary livelihood option to fisher folks whose fish catch had dwindled over the years in Ghana.

Problem Statement

Importing inorganic fertilizers into the country negatively impacts the economy due to high import duties and taxes. Farmers struggle to acquire and use synthetic fertilizers because government subsidies have decreased from 50% to 33% (www.AfricaFertilizer.org). Synthetic fertilizers, when applied, boost crop productivity to meet the growing population's demand (FAO, 2002). However, these fertilizers have significant drawbacks, including high costs, the unpredictability of soils in the tropics and its low nutrient conversion efficiency. Moreover, a significant number of synthetic fertilizer users (farmers) do not conduct adequate soil analysis before the use of these fertilizers. Due to the farmers' activities, the soil becomes more acidic and loses fertility, which lowers crop productivity (FAO/IFA/IFDC, 2003). Furthermore, the buildup of nutrients like nitrogen and phosphorus in surface water bodies as a result of runoff from farmlands from excessive application of synthetic fertilizers caused algal blooms and eutrophication (red tides). These events typically degrade the aesthetic qualities of these water bodies (FAO, 2008).

Every year, huge volumes of *Sargassum* species are washed ashore on the coast of Ghana (Nana Amoasi. Chief fisherman, Elmina Fishermen Association, Personal communication, 2022) and many West African countries (Oyesiku & Egunyomi, 2014). The menace of *Sargassum* species' inundation of coastal West Africa poses economic, social, ecological, environmental, tourism and health problems in coastal communities in the sub-region. Economically, the livelihood of the numerous artisanal fishermen along the coast of the sub-region is affected (Adet *et al.*, 2017). On the sea, the fishing nets of the artisanal fishermen are clogged and the *Sargassum* spp. entangle the

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propellers of their outboard motors. There is generally reduced fish catch, fishing period and income, thereby decreasing women's daily household earnings from processing, distribution, and marketing of fisheries products.

Interestingly, an excellent alternative to inorganic fertilizers is the agricultural applications using the extract of *Sargassum* species (Win & Saing, 2008). Despite the high salinity and presence of naturally occurring tar in the feedstock before treatment, the simple method of incorporating the *Sargassum* into a feedstock has been investigated and no disruptive characteristics have been shown (Sembera, Maier, & Waliczek, 2018). In addition, to promote *Sargassum* use as food or fertilizer, a preliminary investigation into its chemical composition has been done in Nigeria (Oyesiku & Egunyomi, 2014) and the West Coast of Ghana (Addico & deGraft Johnson, 2016). Meanwhile, Abdool-Ghany *et al*. (2023) reported that *Sargassum* composting is increasingly being used as a waste management method, a technique for environmental pollution diversions and also as a useful commodity for agricultural, horticultural and related users (Walker, Walickzek, & Williams, 2006). Furthermore, *Sargassum* seaweed and its by-products have been used to enhance plant growth and productivity in the Caribbean, Texas (USA), Coastal Asia and South East Asia (Eyras, Defosse, & Dellatorre, 2008; Win & Saing, 2008). However, there is limited information on its conversion into compost and co-composted biochar for agricultural applications or useful resource materials in Ghana. The limited information on its agricultural use in the Ghanaian context unearths a dearth of information on the possibility of transforming this potential seaweed into valuable products (compost and co-composted biochar) to be used in improving soil for okra productivity along the coastal savannah zones of the country. It is against this background that this study was undertaken.

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Justification

In order to replenish the fertility of farmers' soils so that crop yield can improve, some farmers use synthetic fertilizers (Tisdale, Nelson, & Beacon, 1990). These synthetic fertilizers when applied increase food production to meet the demand of the rising population (FAO, 2002). However, the use of these synthetic fertilizers had suffered severe limitations due to their high costs, variable nature of tropical soils and low nutrient conversion efficiency. In recent years, researchers have found that there is a significant decline in organic matter content and crop productivity when inorganic fertilizers are applied in an unbalanced way (Kark & Bhattacharya, 2010). Yadav (1998) asserted a linear decline trend in yields of rice and wheat. On the other hand, researchers have found that applying compost has led to significant improvement of soil physical properties such as bulk density, pore size distribution, aggregate stability, soil water retention, hydraulic conductivity and high infiltration rate (Wanas, 2002b, Wanas & Omram, 2006).

The free beaching of the *Sargassum* species therefore provide an important opportunity to explore the possibility of composting and co-composting to meet the agricultural needs of coastal farmers for quality vegetables with high market demand. Consequently, composting the seaweed (*Sargassum* spp.) will release nutrient slowly and promote root development (Barbanti, Grigatti, & Gavatta, 2010), improves soil tilth and increase water holding capacity of substrates (Agegnehu, Bird, Nelson, & Bass, 2015; Aggelides, 2000) and this will increase microbial diversity and provide buffering effect in soils (Kowaljow & Mazzarino, 2007; Xu, Zhao, Yuan, & Jiang, 2012). It is more expedient if farmers are supported to develop their own organic material through composting or co-composting the *Sargassum* spp.

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General objective

To determine the agronomic potential of composted *Sargassum* spp. of varying proportions on the growth and yield of okra in coastal Ghana

Specific objectives

The specific objectives were to:

1. evaluate fishermen's indigenous knowledge of the beaching, management, and socio-economic problems of *Sargassum* spp in Volta, Central and Western regions of Ghana:
2. assess farmers' perception of inorganic and organic fertilizer application, constraints of organic fertilizer use and factors leading to acceptance and adoption of *Sargassum*-based compost:
3. characterize the process and quality of *Sargassum* spp. compost and co-compost:
4. determine the N, P and K mineralization of four *Sargassum* spp. composts in an incubation study:
5. evaluate the effect of *Sargassum* spp. compost in varying proportion on the growth and yield of okra:
6. ascertain the impact of *Sargassum* spp. compost on the soil's chemical properties.

Organization of the thesis

. The thesis was organized into nine chapters. Chapter one covers the background information for the studies that outline trends in the production of vegetable crops generally before focusing on okra production. It also discussed compost and co-composted biochar use, as well as the benefits and drawbacks of using both organic manure and inorganic fertilizers in vegetable crop production. The same chapter highlights the problem statement, which offered the study gap followed by justification,

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objectives and the organization of the study. The literature review and associated literature from books, theses, journals, and conference papers are the focus of the second chapter.

The first objective is covered in brief in the third chapter along with the objectives, materials and methods, statistical analysis, results, discussions and conclusion. Chapters four, five, six, seven, and eight dealt with the 2nd ,3rd ,4th ,5th, and 6th objectives with brief introduction, objective(s), hypotheses, material and methods, results, discussions and conclusions respectively. Finally, chapter nine of the thesis summarized all the study's findings, while conclusion was drawn and recommendations given.

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CHAPTER TWO

LITERATURE REVIEW

The origin and distribution of *Sargassum*

Sargassum fluitans and *Sargassum natans* are two kinds of free-floating *Sargassum* that are never tethered to the seafloor (Trott *et al*., 2011; Schell *et al*., 2015). *Sargassum* species can be found on the beaches of land masses worldwide in warm tropical and subtropical waters (McHugh, 2003). Small amounts of this seaweed can be found on the coasts of Caribbean countries. However, these levels increased dramatically in 2011, 2014 and 2015 in several islands, including Trinidad and Tobago, Barbados and Dominica (Doyle & Franks, 2015). However, the recent *Sargassum* blooms are considered to have originated from east of Brazil in the Atlantic Ocean (Lee Lum, 2015). According to Gower (2013) *Sargassum* is most likely to have originated in Africa.

Biology and growth conditions of *Sargassum* spp.

Large *Sargassum* mats are also used by dolphins for shelter and feeding on fish (Arellano-Verdejo *et al.* 2020). *Sargassum* species that float freely reproduce asexually by fragmentation (Awasthi 2005; Rogers 2011). Warmer oceans, sea temperatures and chemical qualities in their aquatic environment are required to thrive (Round, 1981).

Sargassum is known to develop quickly under the right conditions such as temperature, salinity and nutrients control (Desrochers *et al.*, 2020). According to Wang *et al.* (2019), *Sargassum* was commonly found and blooms in the Gulf of Mexico and it provides food for the Sargasso Sea population. However, *Sargassum* contracts in size as soon as it touches the beach, in just five days, it loses about three times its original volume, turns brittle and transforms from pale yellow to dark brown in colour (Round,

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1981). Numerous Caribbean nations, including Tobago in 2015, Barbados in 2018 and Mexico in 2019, declared states of emergency due to the *Sargassum*'s unparalleled impact (Chávez *et al*., 2020a).

Knowledge and management of *Sargassum* spp by coastal dwellers

According to current reports, the Caribbean saw a distribution of up to 20 million metric tons of floating *Sargassum* biomass, which might potentially beach in the coast of northeastern South America (Wang *et al.*, 2019). *Sargassum* spp. have been a major cause for concern since 2011 when large blooms of *Sargassum* in the Atlantic Ocean threatened marine resources, ecosystems, beaches and populations throughout the Caribbean and West Africa, (Kershaw, 2017; Franks *et al*., 2016, Hinds *et al*., 2016; Wang *et al.*, 2019; Oxenford *et al*., 2021). Nonetheless, between March and September, *Sargassum* spp. was initially observed in Ghana's Western coast (Addico & de Graft-Johnson, 2016). Additionally, it was stated that *Sargassum* spp. entered beaches, lagoons and coastal marine waters in the months of April, May and June before going extinct entirely during the main rainy season (UNEP-CEP, 2021). Furthermore, Asiedu *et al.* (2022) stated that *Sargassum* spp. were primarily found in the Southwestern portion of Nigeria's coast during the rainy season, which runs from May to August. According to Doyles & Franks, (2015) pelagic *Sargassum* is a seaweed that floats freely in the Atlantic Ocean and is easily recognized by most fishermen by its golden-brown colour.

It is possible that Ghanaian fishermen view *Sargassum* species as a waste material. As a result, a large number of coastal communities use their limited resources to clear the *Sargassum* spp. through communal labour. This is in contrast to regions like the Caribbean, where the *Sargassum* spp. are also heavily impacted by the tourism, fishing, water navigation and sport sectors, which turn the *Sargassum* spp. along their

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coast into useful products (Robledo *et al.*, 2021; UNEP-CEP, 2021). According to Abdool-Ghany *et al.* (2023), the economic evaluation of *Sargassum* composting as a method of managing seaweed debris on beaches provided an innovative approach to the management of *Sargassum* in Southeast Florida. It had been reported that money for clearing beaches in Southeast Florida could be more expensive than *Sargassum* composting (Abdool-Ghany *et al*., 2023).

Socio-economic problems of *Sargassum* spp. in coastal communities

Health, tourism and aesthetic problems caused by *Sargassum* spp. to coastal dwellers

Hydrogen sulphide gas produced from decomposing *Sargassum* has been reported to create a harsh odour that keeps coastal dwellers from using the water and beaches and by so changing their way of life (Resiere *et al.*, 2018). Resiere *et al.* (2023) stated that 48 hours after *Sargassum* washes ashore, it usually begins to decompose and release harmful amounts of hydrogen sulphide. According to reports, significant doses of the *Sargassum* such as 50–400 ppm may cause agitation, confusion, nausea, vomiting, increased blood pressure and unconsciousness, myocardial infarction, convulsions, acidosis and even death (Resiere *et al.*, 2021; ANSES, 2017; Resiere *et al*., 2018; Resiere *et al*. 2023). Furthermore, it was confirmed by Kershaw *et al.* (1917) that breathing in low concentrations of extremely poisonous gas carries a danger of death. Environmental aesthetics are lost, and coastal residents' health is severely harmed due to skin irritation and respiratory difficulties caused by highly toxic hydrogen sulphide (Oyeseku & Egunyomi, 2014). Additionally, breathing in little amounts of extremely hazardous gas carries a risk of death (Kershaw *et al.*, 2017). The in-situ decomposition of excessive algal material and groundwater caused by leachates from onshore algal disposal sites contaminate beaches and this impacts the ecology and the

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economic activities developed in coastal areas (Franks *et al*., 2012; Chávez *et al.*, 2020a). With regard to the coastal zone, Ghana's economic growth strategy is to attract both domestic and foreigners to the beach, sun and water (Tweneboah *et al.*, 2009). A portion of the coastal population, whose survival depends on the beaches, benefits financially from tourism. However, the visual impact and odour of *Sargassum* have led to a drop in tourism (Chávez *et al* 2020a).

Ecological problems caused by *Sargassum* spp to fishermen.

Sea turtle nesting areas for example, are impacted according to Kershaw (2017). The discarded *Sargassum* frequently form barriers, preventing turtle hatchlings from reaching the sea. It was reported that turtles seeking to nest were prompted by the environmental bloom of *Sargassum* in China, where *Sargassum* beach landings could impede neonatal hatchlings' ability to survey the sea (Kershaw *et al*., 2017; Maurer *et al.*, 2015). Furthermore, surface blooms impact benthic populations by limiting light penetration through the water column (McGlathery, 2001). Additional negative consequences include fish kills, the inaccessibility of sea turtle nesting sites, the suffocation of coastal organisms like sea grasses and coral reefs, beach erosion and die-off of seagrass beds (Rodriguez-Martinez *et al.*, 2019; Maurer *et al*., 2015; van Tussen Broeck *et al*., 2017). Certain environmental conditions may exacerbate these detrimental consequences such as when fertilizer runoff enriches waters with phosphate and nitrate, causing a surge in the growth of *Sargassum* before it eventually docks and dies (Laporite, 1995). *Sargassum* spp. has a higher negative impact on the coast, near-shore habitats and the communities whose livelihoods depend on having access to the shoreline (Louime *et al.*, (2017). In addition, beaches lost sand due to the heavy machinery used to collect *Sargassum*, which significantly accelerated coastal erosion (JICA & CRFM, 2019).

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Economic problems caused by *Sargassum* spp. to fishermen

In the aquaculture industries, *Sargassum* blooms and beach landings have significant economic effects. For instance, S*argassum* is reported to clog fishing nets and other equipment, restricts fishing grounds, which lowers revenue and raises the cost of maintenance (Solarin *et al.,* 2014; Ramlogan *et al.,* 2017). The literature reports that the presence of *Sargassum* spp. causes some fish species to divert from their typical migration routes or breeding areas, impacting fish densities and abundance as well as the way of life of the coastal dwellers (JICA & CRFM, 2012; Hinds *et al.,* 2016; Ramlogan *et al.,* 2017; Oxenford *et al.,* 2021; JICA & CRFM, 2019). Women's daily family earnings in the processing, distribution, and marketing of fisheries goods will increase whenever there is a reduced fish harvest and a reduced revenue during the fishing period (Adet *et al.,* 2017). This will affect other actors' daily earnings and livelihood in the small-scale fisheries value chain (Adet *et al*., 2017). Since the women are the ones who fund the fishing trip (EFJ, 2022), "no fishing," "no fish," "no money," and "no food" have an impact on everyone, including their families. Not only does the amount of fish catch drop, but fishing effort also decreases (fishing is stopped). It is reported that China's aquaculture industry lost $73 million as a result of seaweed damage (Xing *et al*., 2017). Additionally, it was noted that the clogging of fishing gear by *Sargassum* limits fishing grounds, resulting in decreased earnings and increased upkeep expenses (Ramoglan *et al.*, 2017; Solarin *et al.,* 2014). Consequently, their fish trawlers cannot be drawn ashore or transferred into the sea when *Sargassum* spp. wash ashore. They lost money since several of their fish trawlers went bad, while they were still in the water (Milledge & Harvey, 2016; Chávez *et al.,* 2020a; Louime *et al*., 2017; Adet *et al.,* 2017; Franks *et al.,* 2012).

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Effects of inorganic fertilizers on crops

Organic manures are known to release nutrients slowly while inorganic fertilizers give plants quick access to nutrients when they are needed (Ibrahim *et al.*, 2014). Fertilizer that is inorganic works faster and can be used to balance agricultural needs. They can be applied in large quantities and are less costly than commercial organic manures, according to Ibrahim *et al.*, (2014). Inorganic fertilizers are known to improve the chemical characteristics of the soil through increasing the availability of both macro and micronutrients that are necessary for crops (Prasetyo *et al.*, 2013). High crop productivity is facilitated by chemical fertilizers (Hepperly *et al.*, 2009). Chemical fertilizer meets global standards for food safety by increasing plant growth rate and strength, but it also stunts the development of desirable plant traits like good root and shoot structure and nutritional qualities (Kumar *et al.*, 2019). When more nutrients are provided by inorganic fertilizers in a continuous cropping system, crop productivity cannot be sustained at the intended level, which ultimately impairs the crops' ability to function normally (Thakur *et al.*, 2001).

Land and agriculture are closely related, as most agricultural land is constantly degrading (Toor *et al.*, 2020). Furthermore, excessive application of chemical fertilizers, particularly N can result in crop lodging, bendiness and browning of the crop tips. Overapplication of inorganic fertilizers to plants can cause the leaves of plant to become yellow or brown, kill the plant and give lower crop yield (Nelson, 1984). Because of this, continued usage of inorganic fertilizers will eventually exhaust all biological and natural resources and endanger all forms of life on earth (Kumar *et al.*, 2019).

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Effects of inorganic fertilizers on soil

According to Ilahi *et al*. (2020), the soil serves as a natural medium for plant growth, where soil creatures reside and system nutrients are recycled. When inorganic fertilizers are overused, it can lead to a variety of soil issues such as soil acidification and soil crust disturbance (Ilahi *et al.*, 2020). This can lower the humus and organic matter content in the soil, stunted plant growth and productivity, disturb beneficial organisms in the soil, alter the soil pH, attract more pests and release greenhouse gases. Soil acidity reduces the amount of phosphate, which raises the concentration of toxic ions in the soil (Cooke, 1982). Chemical fertilizers have very negative and irreversible effects on the soil (Sonmez & Sonmez, 2007). According to Laird *et al.* (2010), using only inorganic fertilizers is risky and using them over an extended period of time can contaminate the soil.

Effects of organic manures on crops

Organic manures, including sheep, chicken and farmyard manure may increase crop output (Khan *et al*., 2005). Positive cations, including ammonium ion (NH_4^+), potassium ion (K^+) and magnesium ion (Mg^{2+}) are held by biochar which maintain them in the soil for a long time and releases them when the plants need them (Lal 1982). In degraded soils, it restores crop output more effectively (Jadoon *et al.,* 2003).

The application of phosphorus makes it availability in the soil (Meena *et al.*, 2007). When phosphorus is applied through poultry manure as opposed to other sources, grain yield is maximized. However, when phosphorus is applied through inorganic sources, grain production could increase when phosphorus is applied (Jama *et al.*, 2007). The application of organic manure improves maize grain yield relative to mineral fertilizers (Reddy *et al.,* 2007). Poultry manure releases more phosphorous than other organic materials (Garg *et al.,* 2007). It has been determined that enhanced nutrient

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availability from organic manures caused improved soil nutrient concentration and plant growth (Aziz *et al*., 2010). Additionally, proponents of organic farming claim that compared to conventionally produced plants, plants cultivated with biological nutrient sources are less vulnerable to insect pest attacks (Barna *et al.*, 2015). Furthermore, according to Anderson *et al.* (2005), organic manure is more effective and less expensive than inorganic fertilizer.

Constraints to organic manure use by farmers

Bulkiness, foul odour, sluggish action, transportation difficulty and questionable efficacy have all been identified as constraints linked to using organic manure in crop production (Alimi *et al*., 2006). In contrast, it had been identified that some of the constraints that farmers face when using organic manure are labour-intensiveness, unavailability of manure, higher costs, storage of manures, weed growth and the unpleasant odour (Wheeler, 2008). Pornpratansombat (2010) identified other constraints, such as lack of skills and technical knowledge. Nevertheless, there have been discrepancies and conflicts of ideas regarding the barriers to farmers' use of organic manure. The rules governing the quality control of organic manures, technological difficulties and insufficient or non-existent access to extension services that offer technical guidance are other significant obstacles to the growing use of organic manure. Furthermore, Odhiambo & Magandini (2008) discovered that the primary barrier to the usage of farm yard waste was transportation. This is contrary to reports that the main constraints farmers face with organic manure are questionable efficacy and unpleasant odour (Alimi *et al.*, 2006)

Compost and composting

Stable organic material that has undergone aerobic decomposition is compost (Paulin & Malley, 2008). Composting is described by Food and Agriculture

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Organization (FAO) as a combination of organic waste that is aerobically decomposed to give nutrients and enhance soil structure (Pilar *et al.,* 2015). Typically, dark-brown in colour compost has an earthy scent (Paulin & Malley, 2008).

Composting is the process by which bacteria, actinomycetes and fungi biodegrade a mixture of organic substrate (Insam & Bertoldi, 2007; Hasanimehr *et al.,* 2011; Dickson *et al.,* 1991). Ultimately, according to Pilar *et al.,* (2015) the second-level creatures are eaten by ground beetles and centipedes. Compared to other decomposition systems, composting differs because temperature and decomposition rate are controlled, making available nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) throughout the composting process (Bernal *et al*., 1998; Balasundaran, 2009).

Factors affecting the composting process

According to Mohee (2007), factors such as carbon-to-nitrogen ratio, oxygen supply, temperature, moisture content, particle size and pH of the compost pile all affect the activities of aerobic microorganisms. It is reported that, micro-organisms need 30 parts of carbon for each part of nitrogen, while 20 parts are oxidized to carbon dioxide (CO_2) for energy, 10 parts are needed in the synthesis of protoplasm (Sunar *et al.,* 2009). When the carbon-to-nitrogen ratio is above 20:1 and 35:1, it means N supply is inadequate, dropping heat output, thereby slowing composting pace. During the composting process the carbon is oxidized and the nitrogen is mineralized by microorganisms, hence the starting material's C:N ratio decreases (Mohee, 2007; Hubbe *et al.,* 2010). The pH can increase to 9 during the thermophilic stage, which releases NH_3 and drops to neutral during maturation (Mohee, 2007; Hubbe *et al.,* 2010). EC, a key index can show how the soluble salt concentrations alter during composting. Since salt is phytotoxic and impact crop yield negatively, it is not preferable to have a high

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EC in the compost (Meng *et al.*, 2020). High pH can result from evaporation-induced water loss and a net loss of dry matter from organic matter breakdown (Silva *et al.*, 2009). The leachate's partial loss of salt ions could be the cause of a modest reduction in EC. According to Sunar *et al*. (2009), the O_2 content is correlated with the various gasses present in the compost heap, including O_2, NH_3, H_2S and CO_2 and microbial populations. The high temperatures seen in the tropics can cause compost to dry up quickly. Consequently, farmers must wet the mixture both at the beginning and, if needed, throughout the process to guarantee an appropriate moisture content (Hubbe *et al.*, 2010).

Composting process phases

Mesophilic phase

The compost pile temperature rises to between 35°C and 45°C (Sunar *et al.*, 2009) with mesophilic bacteria predominating. This increase in temperature is attributed to the activities of microorganisms, as during this phase, heat is generated when microorganisms use carbon and nitrogen sources. The breakdown of soluble compounds, such as sugars, produces organic acids, which cause the pH to drop (to about 4.0 or 4.5). The phase lasts for two to eight days (Hubbe *et al.*, 2010).

Thermophilic and hygienization phase

Given its close relationship to organic matter decomposition, the growth of microorganisms and the formation of microbial communities, a primary indicator of compost is considered as temperature (Wei *et al.*, 2022). This phase's temperature is known to rise because of the high-water absorption potential of biochar (Paradelo *et al.*, 2019). At temperatures above 45^{o}C, mesophilic bacteria give way to thermophilic bacteria (Hubbe *et al*., 2010; Pilar *et al.*, 2015; Sunar *et al*., 2009; FAO, 2015). The microbes, mostly bacteria (thermophilic bacteria) that grow at higher temperatures are

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deposited on top of the microorganisms that develop at average temperatures when the feedstock reaches temperatures higher than 45°C (Wang *et al.,* 2020). These bacteria aid in the breakdown of complex carbon sources like lignin and cellulose (Sunar *et al.,* 2009; Pilar *et al.,* 2015; Hubbe *et al.,* 2010). The average pH increases as a result of these microbes' conversion of nitrogen to ammonia. Another name for this stage is hygienization phase because the heat generated kills germs and pollutants that come from the faeces like *Salmonella* spp. and *Escherichia coli* (Insam & Bertoldi, 2007).

Mesophilic phase II or Cooling phase

Once the temperature drops to roughly 40-45^{o}C, the carbon and nitrogen supplies in composting material are depleted. There is overall reduction in microbial activity, the temperature drops (cooling stage) and the compost enters the maturation phase (Pilar *et al.,* 2015). According to Zibilske & Materon (2015), the temperature curves had the same kinetics as conventional composting. The medium's pH slightly drops and mesophilic organisms restart their activity below 40°C, although the pH normally stays slightly alkaline.

Maturation phase

During the maturation phase, which lasts for days at room temperature, side reactions such as polymerization and the condensation of carbonaceous compounds result in the formation of humic and fulvic acids (Pilar *et al.,* 2015; FAO, 2015). Before the compost is sampled for laboratory testing, it is allowed to cure and absorb more water for a certain number of days.

Effects of composting phases on pH

pH is a crucial factor for composting effectiveness, which is connected with the growth, reproduction and physiological metabolism of micro-organisms in the compost (Wang *et al*., (2021). This pH shift was caused by a variety of mechanisms in

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the compost pile, including microbial respiration (Zhang & Sun, 2018; Wang *et al.*, 2021). A pH will sustain microbial activity during composting at a range of 6.7-9.0, according to Wang *et al*. (2020). On the other hand, some researchers have also discovered that anaerobic circumstances (Tautmann & Krasny, 1998) result in a pH decrease at the start of composting, which forms organic acids (Milon *et al*., 2022). Moreover, a high concentration of organic acid, minimal mineralization and sluggish rates of OM/organic N degradation may be the causes of the acidic pH seen during the mesophilic phase I, thermophilic phase, and mesophilic phase II or cooling phase (Ahmed *et al*., 2023; Karak *et al.*, 2013).

Effects of composting phase on electrical conductivity (EC)

The compost's EC indicates how much salt is dissolved (Vicentin *et al*., 2021). Understanding how compost affects plant growth is crucial (Gondek *et al*., 2020). pH levels may drop significantly as a result of certain salt ions being lost in the leachate, particularly in mesophilic phase II. There is a direct correlation between EC and pH levels, with EC rising in tandem with pH (Karak *et al.*, 2013). Elevated EC values pose a risk of salinity in the soil or compost, which may hinder plant development (Abdel-Haleem & El-Shaieny, 2015). Given that salt is phytotoxic and has a negative impact on crop productivity, compost with a high EC is not advised (Meng *et al.*, 2020). Because of the large surface area of biochar, a high EC range releases a significant number of soluble ions and has a greater ability to accumulate various ions (Zhang & Sun, 2017).

Effects of composting process on Ammonium nitrogen (NH_4^+-N) and Nitrate nitrogen (NO_3^--N)

Ammonification converts organic N to NH_4^+-N during composting and NH_4^+-N grew quickly in the mesophilic phase I, although NO_3^--N quantities might stay relatively

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low (Meng *et al*., 2020). Indeed, NO_3^--N generation through nitrification was restricted as a result of the activity and proliferation of ammonia oxidizers, which were likely to be inhibited by the temperature increase and shortage of dissolved oxygen induced by extensive organic matter decomposition (Gao *et al.*, 2010). Since NO_3^--N is easier for plants to absorb and use than NH_4^+-N, an organic fertilizer made of high-quality compost should produce an adequate amount of NO_3^--N (Gross *et al.*, 2011). As a limit for immature compost, values greater than 400 mg/kg of NH_4^+-N were assumed by Zuccani & Bertoldi (1987). The increased values of nitrate nitrogen compared to ammonium nitrogen during the cooling phase (mesophilic phase II) inferred a high degree of nitrification of the organic nitrogen contained in the compost waste. This organic nitrogen is initially released as NH_4^+-N, which is then oxidized to NO_2^--N by Nitrobacter bacteria and then to NO_3^--N by Nitrosomonas (Caurtarella, 2007). Nonetheless, studies revealed that compost made with biochar had a greater NO_3^--N level than compost produced without biochar (Li *et al.*, 2017; Lopez-Cano *et al.*, 2016). Moreover, carbon decomposes at thermophilic temperatures, while nitrogen decomposes at mesophilic temperatures (Zhang & He 2006; Sommer, 2001; Ogunwande *et al.*, 2008).

Effects of composting phase on carbon-to-nitrogen ratio (C:N ratio)

According to Akratos *et al*. (2017) the ideal carbon-to-nitrogen ratio (C:N) is a crucial component of composting performance and may therefore serve as a sign of compost maturity. To keep the microbial population at its most active and speed up composting, a suitable C:N ratio is essential (Martin, 2019). While a lower C:N ratio results in quick nitrogen losses through volatilization or run-off, a higher C:N ratio delays the maturation process. The finished compost's C:N ratio of 14–18 assures a slow mineralization of nitrogen when added to the soil (Akratos *et al.*, 2017).

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Effects of composting phase on moisture content (MC)

The compost's nutritional content and composting outcome are determined by moisture content (MC). Elevated MC prevents the temperature from rising and causes nutritional loss. In contrast to Manyapu *et al*. (2017), who found that, MC needed to be in the 15–25% range at the conclusion of composting, Rynk *et al*. (2022) stated that MC should be in the 50–65% range during the beginning of the composting process to limit the loss of nutrients. Moisture mostly affects temperature and aeration (Boulter *et al.,* 2000).

Decomposition of organic waste using biochar

During composting, organic matter is transformed by the action of microorganisms into stable humus (Wu *et al.*, 2017). Stable organic materials, including amino acids, simple carbs and lipids decompose swiftly during composting early phases (Akdeniz, 2019). Other organic matter types such as lignin, hemicellulose and cellulose break down slowly, and this reduces the compost's effectiveness and lowers the quality of the finished product (Bernal *et al*., 2009; Yin *et al.,* 2019a; 2019b). Numerous studies have demonstrated that exogenous additives like zeolite (Wang *et al*., 2017), wood vinegar (Guo *et al.,* 2020a; 2020b), superphosphate (Zhang *et al.,* 2017) and biochar (Akdeniz, 2019) enhance the decomposition of organic matter and boost compost's efficacy as a fertilizer. This is because biochar can increase compost's aeration (Godlewska *et al*., 2017) and boost the activities of microorganisms and enzymes (Yin *et al.,* 2021). Furthermore, it encourages organic materials to degrade. It can decrease the period of composting and improve the compost product by speeding up the mineralization of organic waste (Wang *et al.,* 2017; Sanchez-Garcia *et al.,* 2015; Khan *et al.,* 2016). For instance, studies found that composting with biochar increased the number and variety of microorganisms (Yang *et al*., 2020). Yin *et al.* (2021) discovered

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that bamboo charcoal enhanced the activities of urease and cellulose by 96 and 56% respectively, during the composting of chicken manure. Additionally, by adsorbing reactor chemicals like H_2S, NH_3, NH_4^+ and SO_4^{2-} the breakdown of organic materials, is hastened by biochar (Akdeniz, 2019; Zhang *et al.*, 2016). Li *et al.* (2015) reported that, organic matter degradation rate increased by 14.8–29.6% when they added biochar to pig manure during composting. On the other hand, adding biochar to compost has been found to speed up the breakdown of organic materials while also boosting carbon dioxide emissions (Czekala *et al.*, 2016). The addition of 10% (dry weight) biochar increased carbon dioxide emissions by 7.4% compared to composting without biochar (Awasthi *et al.*, 2020).

Effects of biochar on nitrogen transformation during composting

Proteins, urea, and amino acids are some of the sources of organic nitrogen that is present during the initial phases of composting (Sanchez-Monedero *et al.*, 2018). Organic nitrogen is then transformed to NH_4^+, which is then turned to NO_3^- by nitrifying bacteria (Yin *et al.*, 2019a). It is possible for some nitrogen to escape the composting pile as NH_3 and N_2O. Conversely, a significant quantity of nitrogen might limit the compost product's effectiveness as fertilizer and have adverse effects on the environment when it volatilizes as gas (Yang *et al.*, 2015; Maeda *et al.*, 2011).

Biochar's aromatic molecules may react with NO_3^- (Zhang *et al.*, 2018). Biochar can influence nitrogen transformation by changing the microbial community structure during composting (Godlewska *et al.*, 2017). Vandecasteele *et al.* (2016) found that the final compost product obtained without adding biochar had a 29% higher NH_4^+ content. Biochar's acidic functional groups affect the total nitrogen concentration of the compost. Pig manure quality was found to be enhanced by adding 2-10% (dry weight) bamboo biochar (Awasthi *et al.*, 2020). The final product's NO_3^- level was increased by 38.8–

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152.6 % with compost. Furthermore, compost generated with biochar had a much greater NO_3^-level than compost produced without biochar (Li *et al*. 2017; Lopez-Cano *et al.*, 2016).

Effects of biochar on nitrogen mineralization, immobilization and nitrification

Microbes are responsible for the immobilization or adsorption of NO_3^--N on biochar (Clough *et al.*, 2013). The following are some possible ways that biochar influences N cycle of the soil: (1) N adsorption or desorption by biochar to change the amount of inorganic N in the soil (2) modifications to the content of labile organic compounds or soil mineralizable substrates to influence the microbial processes of N mineralization or immobilization; (3) adjustments to soil properties such as pH and aeration to modify the equilibrium between the nitrification and denitrification processes (Dai *et al*., 2020). Generally, low-temperature-pyrolyzed biochar adsorbs more NH_4^+-N than high-temperature-produced biochar because of the acid functional groups and labile carbon on its surface (Nguiyen *et al*., 2017). Furthermore, there is no discernible trend in the pyrolysis temperature, although ammonium removal rates exhibit significant variations (Yao *et al.*, 2012). The CEC of the biochar is typically mentioned as causing the adsorption of NH_4^+-N onto the biochar and the observed reductions in NH_4^+-N leaching, similar to soils and demonstrating its capacity to electrostatically sorb or attract cations (Clough *et al*., 2013).

Maturity assessment of compost

The stability and maturity of compost have been evaluated using a number of different criteria (Antil *et al.*, 2012; Bernal *et al.*, 2009; Raj & Antil, 2011). However, no single method can be utilised for all types of compost because materials and composting procedures differ (Benito *et al.*, 2003; Itavaara *et al.*, 2002; Chang & Chen, 2010). Compost maturity is indicated by several metrics, including the carbon-to-

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nitrogen ratio, germination indices, NH_4^+/NO_3^- ratio, NH_4^+-N concentration and CO_2 evolution. There are currently no internationally accepted standards for compost maturity specification since the values of the various qualities of mature compost vary with the feedstock from which the compost was formed (Bernal *et al*., 1998; Mathur *et al*, 1993; Warmen, 1999).

Very mature and immature final NH_4^+/NO_3^-a ratio of <0.5 from 0.5 to 3.0 and >3.0, respectively were reported by Das *et al.* (2011). On the other hand, maturity is indicated by NH_4^+/NO_3^- ratios of less than 0.16 and NH_4^+-N levels of less than 0.04 % (Bernal *et al.*, 1998; Pare *et al.*, 1997). It is believed that stability is demonstrated by CO_2 evolution of less than 1 mg CO_2-Cg [dw]d^{-1} (Thompson *et al*., 2003; Wang *et al.*, 2004). Furthermore, research indicated that, compost maturity was indicated by a C:N ratio of less than 20, with 15 or less ratio being desired (Bernal *et al.*, 2009). However, Sellami *et al. (*2008) and Goyal *et al.* (2005) have pointed out that compost maturity cannot be assessed just by the carbon-to-nitrogen ratio.

The impact of nitrogen and carbon dynamics on compost quality

During composting, nitrogen supplies the energy needed to break down carbon. Carbon is used to make up half of the biomass produced by microbes. Brewer & Sullivan (2001) reported that feedstock with a higher decomposable C content promotes higher microbial respiration rates. Water-soluble hydrolysate C, which makes up one-third of the material lost during composting, is accessible to microbes. This suggests that a decrease in water-soluble carbon is a sign that compost is matured, which can be used as fertilizer or as nurseries (Brewer & Sullivan, 2001; Gao *et al.*, 2010; Boulter *et al.*, 2000). A lignified feedstock with higher tannin concentrations may be the cause of the low C breakdown that occurs during composting (Bakry *et al.*, 2012). By the time composting is completed, NO_3^--N levels need to be higher than NH_4^+-N levels (Xiying

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Hao, 2007). A 0.16 is the standard for the ratio of NH_4^+-N to NO_3-N (Gao *et al.*, 2010). Other reports stated that, N decomposes at mesophilic temperatures, while C decomposes at thermophilic temperatures (Zhang & He, 2006; Sommer, 2001; Ogunwande *et al.*, 2008). Additionally, Leconte *et al*. (2011) reported that the sawdust and rice husk-based compost containing poultry manure had higher quality in terms of N and P. Bacteria that oxidize ammonium are less active in environments with higher pH and more NH_4. The EC and pH levels are affected by the NH_4 and NO_3 fluxes (Kato *et al.*, 2005).

Chemical characteristics of matured compost

Mature compost has different properties depending on what kind of material it was made of, therefore, as of now, there are no internationally recognized standards for defining compost maturity (Warmen, 1999; Mathur *et al.*, 1993; Bernal *et al.*, 1998). However, Amlinger *et al.* (2003) found that nitrogen mineralization is impeded at pH levels greater than or equal to five in mature compost. According to Eghball (1997), compost should have a pH between 6.5 and 8.0. However, Sullivan *et al.* (2003) reported that the level of pH for compost quality is 7.0-8.0, which is in the best range for microbial activity, while Kizza-Nkambwe *et al.* (2023) also observed a pH level of 9.0 during compost quality assessment of peri-urban trash in Uganda. Deviation from the ideal range may affect the final compost's quality because the activity of the composting bacteria depends on pH (Jalalipour *et al.*, 2020).

According to Sembera *et al.* (2018), although there was high salinity and the presence of naturally occurring tar, the straightforward process of adding *Sargassum* spp. into feedstock had been studied and no disruptive characteristics were found. In the meantime, increasing phytotoxicity has been connected to higher EC in mature compost (Wilson *et al.*, 2001). It is reported that the increase in electrical conductivity

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could be as a result of the release of mineral salts during the active phase of composting (Gomez-Brandon *et al*., 2008). The researchers proposed that compost containing K, Mg, Ca and NO_3 would have a moderate EC. However, the presence of Na and Cl_2 will cause compost to have a high EC, which will be harmful to plants. Compost with an EC greater than 5 µS/cm should be administered at lower concentrations or utilized as mulch for established plants, according to Brewer & Sullivan, (2001). According to Vandecasteele *et al.* (2016) the final compost product produced without biochar had an NH_4^+-N content that was 29% greater high.

Earlier studies indicated that the ratio of NH_4^+-N:NO_3^--N less than 0.16 and an NH_4^+-N concentration of <0.04% could signify maturity of compost (Pare *et al*., 1997; Bernal *et al*., 1998). Additionally, according to Xiying Hao (2007), NO_3^--N levels ought to be greater than NH_4^+-N during composting, According to Golueke (1977), a stable, mature compost is generally thought to have a carbon-to-nitrogen ratio of less than 20. When *Sargassum* compost reached maturity, Walsh (2019) found that the C:N ratio was less than 20. Total N value was observed by Sullivan *et al*. (2003) to a range between 0.7% and 1.5%. Total N is released by bacteria during active composting and fixed in the compost matrix to ensure its preservation, making up majority of N the compost release during mineralization (Maynard, 1994).

Furthermore, the original composition of poultry manure increased the functional exchange groups, which may have contributed to increases in TOC contents and the high CEC value (Sartor *et al.*, 2012).

Effects of compost mineralization in soil on pH after incubation.

The pH of soil modified with compost increases (Abera *et al.*, 2012). Liyanage *et al*. (2015), however, reported that quick nitrification would result in a pH drop in the soil. Numerous studies have demonstrated that adding organic manure to the soil raises

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its pH. Opala *et al.* (2012) demonstrated that combination of farmyard manure (FYM), *Tithonia* leaves and inorganic P sources increased soil pH, while reducing exchangeable acidity. Abera *et al.* (2012) asserted that, the alkaline nature of plant residues which generate base cations when legume residue is added under varying soil moisture regimes may be the cause of this pH increase. Numerous studies have suggested that the natural alkaline nature of biochar could act as a liming agent and raise the pH of the soil, particularly in acidic soils (Tsai & Chang, 2020a; Tsai & Chang, 2020b; Tsai & Chang, 2020c; Jefferey *et al*., 2011; Yu *et al*., 2021). According to Robertson & Groffman (2007), for soil microbial oxidizers, the optimal pH range is 7.0-7.9.

When NH_2-N is converted to NH_3-N and the subsequent removal of H^+ protons from the medium to change NH_3-N into NH_4^+-N, which raises the OH^- concentration and momentarily raises pH, could be the cause of the pH increase (Havlin *et al.*, 2016). The quick change of NH_4^+-N to NO_3^--N in sandy loam soil treated with inorganic fertilizer causes a pH decrease (Fageria & Nascente, 2014; Havlin *et al.*, 2016).

Effects of pH on nitrogen, phosphorus and potassium mineralization after incubation

The main factor influencing the nitrogen cycle is the pH of the soil, which includes mineralization and nitrification (Sahrawat, 2008; Curtin & Trolove, 2013). It was previously thought that these processes have their optimal pH around 8.0 and do not occur at all in pH lower than 5.5 (Sahrawat, 2008). Nonetheless, nitrification has previously been demonstrated to occur in very acidic soils (Head *et al.*, 1993; DeBoer & Kowalchuk, 2001; Gubry-Rangin *et al.*, 2010).

According to Haynes (2001), the release of hydrogen ions during nitrification causes soil organic matter to lower soil pH. According to Liang *et al.* (2006), ammonia volatilization promotes nitrogen loss when the pH is higher than 7.5. Additionally,

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Rigby *et al.* (2016) found that when pH values were elevated from acidic to slightly alkaline range (<pH 8), the rate of N mineralization increased with soils supplemented with compost.

Effects of compost mineralization on electrical conductivity (EC) after incubation

Hirzel *et al*. (2023) reported increased EC value when sandy loam soils were amended with three types of compost. According to Havlin *et al.* (2016), when EC values in sandy loam soils are below the agronomic critical level, there is no risk to species that are grown for agricultural purposes. Furthermore, free ion concentration in the solution is decreased by the expansion of soil biomass and its involvement in these processes (Teutscherova *et al.*, 2017; Hartz *et al.*, 2000; Hirzel, Undurraga & Walter 2010).

Effects of compost mineralization on ammonium nitrogen (NH_4^+-N) after incubation

The total amount of NH_4^+-N and NO_3^--N is known as the available N content. Ammonium nitrogen and Nitrate nitrogen are the forms of N available to plants and microorganisms (Zhang *et al.*, 2015). Since most of the nitrogen that plants assimilate comes from inorganic pools (NH_4^+-N and NO_3^--N), the rate at which organic nitrogen decomposes and mineralizes to inorganic nitrogen is a major factor, which will regulate the amount of N supplied to crops (Zhang *et al.*, 2015). The rate at which organic nitrogen breaks down and becomes inorganic nitrogen is determined by the type of fertilizer (chemical or organic), soil moisture content and temperature (Hossain *et al.*, 2017). Rapid ammonification is related to the resilience of heterotrophic bacterial activity (Abera *et al*., 2012). Liyanage *et al*. (2021) reported that the higher N content and lower C:N ratio in compost-amended soil accelerated the decomposition and mineralization. Meanwhile, Baldi & Tosseli (2014) also reported incubation of compost

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amended soil as ammonification occurred maximally on day seven after the incubation. On the other hand, Walpola & Arunakumara (2010) found that the NH_4^+-N peaked on day 15 and then gradually decreased with all treatments. Baldi & Toselli (2014) reported a similar outcome in their experiment involving the incubation of organic manure. Depending on the prevailing soil condition, NH_4^+ mineralized from organic supplements can be retained by soil components, temporarily immobilized by soil bacteria, further transformed into nitrate or even lost as NH_3 (g) (Azeez & van Averbeke (2010).

Effects of compost mineralization on nitrate nitrogen (NO_3^--N) after incubation

In aquatic and terrestrial ecosystems, nitrification is carried out by a limited group of nitrifying chemo-lithotrophic bacteria and archaea. It occurs when ammonium ions (NH_4^+-N) are oxidized to nitrate ions (NO_3^--N) (Head *et al.*, 1993; De Boer & Kowalchuk, 2001). Since plants prefer to absorb NH_4^+-N and NO_3^--N, this mechanism is crucial to make nitrogen (N) available to plants. Since soil acidification is also caused by nitrification, certain measures that lower nitrification rates may help improve soil quality because there is a chance that NO_3^--N will be contaminated. It is reported that N mineralized rapidly in manure-treated soil during the 56–84-day incubation period (Ling-ling & Shu-tian, 2014). Generally, nitrification was higher and NO_3^--N immobilization was lower (Abera *et al.*, 2012).

Effects of compost mineralization on carbon-to-nitrogen ratio (C:N) after incubation

Low nitrogen availability in the soil is a result of immobilization being greater than mineralization by microorganisms (Islami *et al.*, 2011). According to Chen *et al.* (2021), low mineralization resulting from the compost's high C:N content is as a result of the lack of responsiveness of total N to co-composted biochar soil additions.

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Masunga *et al*. (2016) reported that microbial immobilization and poor mineralization following adsorption into biochar suggested that the C:N ratio exerts a stronger effect on ammonification. Regarding the amounts of C and N available for microorganisms, the C:N ratio governing the balance between N mineralization and immobilization can occur simultaneously within a small volume of soil (Robertson & Groffman, 2007). There have been reports of N immobilization after adding compost or biochar with a high carbon-to-nitrogen ratio (Hailegrow *et al.*, 2019; Li *et al*., 2010; Ameloot *et al.*, 2015; Signa *et al.*, 2016). Biochar C:N ratio being more than 20 (Nguiyen *et al*., 2017; Chan & Zu, 2009) and/or 32 (Nguiyen *et al.*, 2017; Kuzyakor *et al.*, 2000) will lead to N immobilization with initial net immobilization of N (Borchard *et al.*, 2012). Eldridge *et al*. (2017) reported that the C:N ratio of compost should be less than 20.

Effects of compost mineralization on available phosphorus (P) after incubation

Organic P exists in different forms such as non-labile phospholipids, inositols and orthophosphate diesters, which are more resistant to degradation (Dao, 2004; Silveira, Miyittah, & O'Connor, 2006; Verma, Subehia, & Sharma, 2005). They are also responsible for the formation of a colloidal clay-humus complex (Chatterjee, Datta & Manjaiah, 2014; Havlin *et al.*, 2016), which could account for the lower relative P availability when using compost. Microbes may also reabsorb the P released during compost mineralization and immobilize it in biochar (Chen *et al.*, 2021). Apart from the immobilization of microorganisms, the component of P mineralization might be bonded again into organo-complexes (Jalali *et al*., 2014).

Furthermore, depending on pH, mineralized P may reach Ca/Mg carbonates or Fe/Al and become inaccessible. Nonetheless, Naher *et al.* (2004) found that after applying organic manure for 15 days, P mineralization started to increase and with time.

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Higher P mineralization was discovered by the aforementioned researchers in the compost treated with cattle manure and chicken manure (Naher *et al.*, 2004).

According to Ahmad *et al.* (2019), biosolids or wastewater products have positive environmental impacts are used as a soil nutrient amendment through the mineralization and mobilization of P. Due to the simultaneous mineralization-immobilization process, microbial P immobilization momentarily prevents soil P from being accessible to plants to absorb. Nevertheless, it eventually becomes available with completion of microbial decomposition (Kirkby *et al.*, 2014; Johnson, 2012). According to Zhang *et al.* (2020), P fertilizer quickened the cycle of organic matter (SOM), which may help paddy soil's ability to sequester carbon.

Effects of compost mineralization on available potassium (K) after incubation

In order to determine the availability of phosphorus, potassium and nitrogen in three compost and two fertilizers, Hirzel *et al.* (2023) reported lower values of potassium on day 0 of their 120-day incubation period. As reported by some authors (Bustamante *et al.*, 2011; Jiménez Becker *et al.*, 2010), a higher efficiency of the increase in the K concentration would have been expected when using compost, however, there was a high possibility of K fixation capacity of clay loam soils as reported in the literature (Havlin *et al.* 2016; Chatterjee, Datta & Manjaiah, 2014).

Furthermore, faster K delivery from the organic manure and K desorption processes facilitated by the soil's moisture and temperature during incubation were indicated by the greater K increase efficiency value (Portela *et al.*, 2019; Havlin *et al.*, 2016). Samuel *et al.* (2003) reported that the presence of K^+ frequently restricts NH_4^+-N because K^+ can fill fixation sites.

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Climatic requirement for the growth and storage of Okra

Okra is a warm-season crop that thrives between the minimum and highest mean temperatures of 18°C and 35°C, respectively (Ezeakume, 1984). Low temperatures affect okra growth, as it grows poorly below 15ºC (Marsh, 1992). It can tolerate acidic, rainy and poorly drained soils (Incalcaterra & Curatolo, 1997). A 24° to 32°C is the ideal soil temperature for seed germination (Martin *et al.*, 1983). At 20ºC or lower, germination is weak. Most varieties are stimulated to blossom by short days (Martin *et al.*, 1983). When the days are longer than 11 hours, flowering begins relatively early in the plant's growth cycle. Long days cause the flower buds to frequently fall (Chauhan, 1972). It requires 5–14 days for germination (Hamon *et al.*, 1991). Although the vegetable can be preserved for several days, it is best consumed shortly after picking. If kept at 45°–50°C and 90%–95% relative humidity, okra lasts 7–10 days (Martin *et al.*, 1983).

Influence of compost on growth of okra

It has been demonstrated that compost increases sandy soils' nitrogen concentration threefold (Schulz *et al.*, 2014). Plants require specific amounts of these nutrients for certain functions (Njoku & Ebeniro, 2009). Compost enhances plant growth in soils (Tiamiyu *et al.*, 2012; Akanbi *et al.*, 2010). Furthermore, higher pH, electrical conductivity and soil fertility can lead to greater okra growth (Solomon *et al.*, 2007; Lehmann *et al.*, 2003; Liang *et al.*, 2006). Additionally, compost is made up of materials that have disintegrated very quickly due to regulated aerobic biological breakdown of organic matter (Storey, 1995; Epstein, 1997). Roesmakam & Yuwono (2002) reported that applying organic fertilizers could easily improve soil structure and allow plant penetration. They stated that organic manure would release nutrients for a

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plant with complete N, P, K, Ca, Mg, S and micro nutrients. Consistent with the findings of other studies, larger stem diameters of okra may confer great resilience to strong winds and other climatic variables, which may induce logging (Joshi *et al*., 2021; Mehta *et al*., 2017; Okoli, 2021)

Sargassum-based fertilizers have been shown to boost crop yield in various agricultural production systems (N'Yeurt & Less, 2014; Crouch & van Staden, 1993). Additionally, compost releases nutrients and promotes root development (Barbanti *et al.*, 2010), enhances soil tilth and increases soils' water-holding capacity (Agegnehu *et al.*, 2015; Aggelide, 2000), increases diversity of micro-organisms and provides a soil buffering effect (Agegnehu *et al.*, 2015; Aggelide, 2000; Kowaljow & Mazzarino, 2007; Xu *et al.*, 2012). All the above factors lead to plant growth and development. According to Ajari *et al.* (2003), in the production of okra, organic manure could increase crop height compared to other manure sources. Tivelli *et al.* (2013) also reported a mean okra plant height of 160.9 cm when intercropped with small size leguminous species. According to Dademal *et al.* (2004), N content in organic fertilizer enhances leaf production, seed formation and root formation. Poultry manure in compost contains relatively high nitrogen content and support more vegetative crop growth (Akanbi *et al.*, 2005). Since okra height is genetically influenced, the significant increase in internode length is directly proportionate to plant height and it is attributed to genetic traits (Amanullah *et al.*, 2010). Gruhn *et al.* (2000) stated that using compost to amend soil offers numerous benefits such as improvement in soil aggregate stability. Storage compounds (ATP and ADP) formation results in increased cell growth activity and provides cells with energy (Sarchan *et al*., 2017).

Broader leaf areas are a desirable agronomic trait in okra, as they demonstrate the ability of the plant to absorb more sunlight for efficient photosynthetic activities

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(Oworu *et al.*, 2010; Joshi *et al.*, 2021; Dimkpa *et al.*, 2019). In okra cultivation, Ibrahim & Hamma (2012) reported that organic manure could increase the crop's leaf area, plant height and branches. According to Bandyopadhyay *et al.* (2001), okra cv *Parbhani Kranti* plants yielded the broadest leaf area and growth rate in comparison to other cultivars. Research by Sharma (1995) revealed that leaf chlorophyll content was higher when doses of NPK were applied, leading to an uptake of magnesium, the chlorophyll central molecule. Additionally, Sutpal & Saimbhi (2003) posited that N and P supply increased the uptake of magnesium leading to the formation of more photosynthetic structures such as chlorophyll.

Influence of compost on yield of okra

Singh *et al*. (1996) found variations among okra varieties for flowering. They found that the variety *Arka Anamika* required longer days for the first flowering date. There is always variation in flowering, possibly due to seasonal variations in temperature, day length and humidity. Research by Rajesh *et al*. (2018) suggested that, the early flowering genotypes could be useful for multiple year-round production thereby ensuring sustainable okra production, and improving farmers' livelihood.

Report indicated an increase in the yield of okra plants sampled from plots supplemented with different types of organic manure, including compost and this results in an increase in pod length, girth and fresh pod weight of okra (Ofosu-Anim *et al.*, (2006). According to Agarwala *et al.* (1981), and Tisdale *et al*. (1990) the increased soil's capacity to retain water and available nutrients in the manured plots might have provided support for the plants. Effiong *et al.* (2009) also reported that soil supplemented with compost resulted in improved yield and nutrient uptake of crops. When okra variety such as LD 88 was used as a test crop, Uwah *et al*. (2010) found that okra requires 80 kg N ha^{-1} of compost for a good yield.

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Other studies have reported that to record good yield of crop depends on the cultivar used, moisture content, soil type and the nature of compost (Bisht & Bhat, 2006). Shridhar (1996) and Singh *et al.* (1996) asserted that an okra cultivar generated the highest number of fruits (12.0). However, the mean number of fruits harvested by Oliveira *et al.* (2007, 2014) was 43 and 26 fruits per plant, respectively. A greater proportion of fruit-bearing flowers could perhaps account for the increased fruit set (Premsekhar & Rajasree, 2009). Applying compost causes an increase in fruit weight. The movement of photosynthates from the source to the sink of plants, which is affected by growth hormone and released or synthesized as a result of the organic fertilizer source, is what causes the rise in fruit weight (Susan, 1995; Mal *et al.*, 2014).

The impact of *Sargassum* compost on soil chemical properties grown to okra pH

By producing base-forming cations, the application of compost raises the pH of acidic soil (Leroy *et al.*, 2007; Erhart & Hartl, 2010). According to Banuwa *et al.* (2020), the mineralization of compost releases alkaline cations, hence, applying a significant amount of compost even continually raises the pH of the soil. Numerous studies have documented increased pH in soil with added compost (Castilo *et al.*, 2004; Buttler & Muir, 2006). The complicated capability of the compost for humic acids may result in a decrease in polycation levels (Fe and Al) and an increase in exchangeable bases (Bulluck *et al.*, 2002). Furthermore, it enhances soil stabilization by maintaining or increasing buffer capacity (Leifeld *et al.*, 2002). Liu *et al.* (2021) and Wang *et al.* (2019) stated that adding organic manure to these soils could increase their pH.

Electrical conductivity (EC)

Microbial activity during the breakdown of organic manure might lead to the production of particular organic acids, which are necessary for solubilizing inorganic fertilizers. The soluble salts that are released into the soil could increase the soil's

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electrical conductivity. According to Mussaddiq *et al.* (2019), soil pH and EC variations occur after adding organic manures and mineral fertilizers. Additionally, adding green compost enhanced the soil's pH and EC, according to Sarwa *et al.* (2010).

Organic carbon (OC)

Compost raises the amount of organic carbon in the soil when added. According to Michael *et al.* (2012), adding kraal compost to the soil raised its organic carbon content. Their findings, however, is contrary to those of Wahba (2003) and Celik *et al.* (2004) who discovered that adding compost did not increase SOC levels. However, using compost created from manure and household waste increased organic carbon significantly and the most successful method was the compost treatment (Bouajila & Sanaa, 2011).

Total nitrogen (TN)

The increased microbial activity changes organic N in the soil into an exchangeable form. Ndor *et al*. (2015) posited that combining organic manures with mineral fertilizers can increase the amount of soil organic matter and nitrogen content. In addition, Hernández *et al.* (2016) found that applying compost could improve the TN nutrients needed by plants, when lettuce crops was planted. Bouajila & Sanaa (2011) reported that applying compost of 40 and 120 t/ha increased the amount of N in the soil.

Available phosphorus (P)

According to Stevenson (1986), salinity, aeration (availability of oxygen), and soil moisture are a few variables that influence how quickly phosphorus mineralizes from organic matter breakdown. Another possibility is that adding compost to the soil raised its pH, which improved the availability of phosphorus (Tubeileh & Stephenson, 2020). Phosphorus availability in the soil is best regulated in the pH range of 6.0 to 7.5, but other factors like soil response, clay mineralogy, and fertilizer management may

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also play a role (Tisdale *et al.*, 1990). It is also important to maintain organic matter (Schlecht *et al.*, 2006). Conversely, Alley & Vanlauwe (2009) reported that precipitation of Al and Fe ions causes plant nutrients such as P to be less accessible in acidic soils.

Exchangeable cation (K^+, Na^+, Mg^{2+}, Ca^{2+}) and exchangeable acidity (Al^{3+} H^+).

According to studies, a pH of 6.5 may make calcium less available, whereas a pH of 7.5 to 8.5 may cause the Ca-PO_4 combination to develop and decrease calcium availability (Stevenson, 1986). The slow release of nutrients necessary for plant usage and nutrient mineralization may also be responsible for increased available nutrients (Olaniyi & Odedere, 2009). Studies have shown that the addition of compost to soil can increase its CEC, thereby increasing the number of exchangeable cations in the soil (van Wambeke, 1992). Moreover, increases in compost addition are reported to raise levels of phosphorus, potassium, calcium and magnesium in soils, while compost additions decrease levels of Na (Schulz *et al.*, 2014). Tubeileh & Stephenson (2020) discovered that compost increased levels of potassium, phosphorus and other micro elements in the soil.

Effective cation exchange capacity (ECEC)

As soil acidity increases, cations such as H^+, Al^{3+} and Mn^{2+} are replaced (Erhart & Hartl, 2010). Organic matter increases the amount of stored organic carbon in the soil and as a result, ECEC is essential for plants to take up and utilize nutrients (Diacono & Mantemurro, 2010; Mwiti Mutegi *et al.*, 2012). Adugna (2016) asserted that the mineralization of compost releases potassium, calcium and magnesium into the soil, among other nutrients, greatly enhancing the soil's nutrient content.

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CHAPTER THREE

INDIGENOUS KNOWLEDGE OF FISHERMEN ON BEACHING, MANAGEMENT AND SOCIO-ECONOMIC PROBLEMS OF SARGASSUM SPP. IN VOLTA, CENTRAL AND WESTERN REGIONS OF GHANA

Introduction

Sargassum is known to occasionally occur in the Caribbean and the Gulf of Mexico, where it became abundant in the spring and feeds the Sargasso Sea population via the Gulf Stream current (Wang *et al.*, 2019). It is essential to the life cycle of certain marine creatures in this region. Commercial fish, birds and humpback whales all migrate across the Sargasso Sea each year in search of *Sargassum* for food. Sea turtle hatchlings receive nourishment and shelter from the *Sargassum* mats (NOAA, 2021). Many marine animals have adapted to dwell inside the mats such as fish, crabs and shrimp (Coston-Clements *et al.*, 1991).

On Ghana's Western coast, *Sargassum* was first discovered in 2009, according to Addico & de Graft Johnson. (2016). However, the first notable influx was observed between 2011 and 2012 (Marsh *et al.*, 2021; Ackah-Baidoo, 2013; Fidai *et al.*, 2020). Since that initial survey, there has been an annual increase in the densities of the flooded *Sargassum* spp. Insufficient empirical information has been gathered to clarify the causes of the beaching of the *Sargassum* spp. and the magnitude of its impact on the ecosystem and coastal populations, even though it has been a consistent feature for more than ten years. The continuance of the migration has become an issue for coastal residents whose livelihoods are based on fishing and the ocean.

Hydrogen sulphide gas generation from decomposing *Sargassum* has been reported to create a foul stench that discourages coastal dwellers from accessing both ocean and beaches, thereby affecting their way of life (Resiere *et al.*, 2018).

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Moreover, among its many potential applications are building blocks such as animal feed, biofuel energy, soil fertilizer, bioplastic and pharmaceuticals (Milledge *et al.*, 2016; Chávez *et al.*, 2020b; Thompson *et al.*, 2020). However, there is little information on how knowledgeable indigenes were about the beaching, management and socio-economic problems of these *Sargassum* spp. The chapter, therefore, examines the coastal communities' indigenous knowledge of *Sargassum* spp. and how impactful *Sargassum* spp. had been on their socio-economic livelihood.

Objective

To assess fishermen's indigenous knowledge of the beaching, management, and socio-economic problems of *Sargassum* spp. in the Western, Central and Volta regions of Ghana.

Hypotheses

Ho: Coastal communities have limited knowledge about the beaching, colour, texture, structure and volume of *Sargassum* spp. on their coast.

Hi: Coastal communities have adequate knowledge about the beaching, colour, texture, structure and volume of *Sargassum* spp. on their coast.

Ho: Coastal communities do not have adequate knowledge of management and socio-economic problems of *Sargassum* spp.

Hi: Coastal communities have adequate knowledge of management and socio-economic problems of *Sargassum* spp.

Materials and Methods

Description of Western Region study areas

South of Ghana is where the Western region is situated (longitude 2°12'45.577'W and latitude 5°11'48.003'N). The Central region borders it to the east, while Cote d'Ivoire borders it to the west. Its borders are the Atlantic Ocean (Gulf of

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Guinea) to the south and the Western North region to the north. It contains Cape Three Point; Ghana's southernmost point where abundant crude oil was discovered in June, 2007. At the time of the 2021 housing and population census, the region's area was 13,842 square kilometres and its population was 2,060,585. Ghana's Western region boasts beautiful green hills, healthy soil and the most rainfall. It is located in Ghana's upper forest zone where 75% of the flora is found and it has mild temperatures typical of the tropical climate. It receives 1600 mm of rain on average per year. Nonetheless, the Western region's average yearly rainfall in 2022 was 1800 mm (MoFA, 2022). A 90% of the air is humid at night and 75% during the day.

Names of study areas (districts and communities) in the Western Region

The four districts picked in the Western region for the survey were Shama, Secondi/Takoradi Metropolitan District, Nzema East and Ahanta West. Six communities in the Western region were chosen to interview fishermen. These were Shama, Ngyiresia, Sekondi, Akwidaa, Dixcove and Axim. The communities were chosen based on their track record of fishing over the years.

Description of Central Region study areas

The Central region is located at latitude 5°28'43.519"N and longitude 0°15'21.425"W. Ashanti and Eastern regions border it to the west, Greater Accra region borders it to the east and to the south by the 168-kilometre-long Gulf of Guinea. At 9,826 square kilometres or 41% of Ghana's total land area, it is the third-smallest region in terms of area, behind the Upper East and Greater Accra regions. The annual precipitation varies from roughly 2000 mm in the interior to 1000 mm toward the shore. Nonetheless, the Central region's mean annual rainfall in 2022 was 800 mm (MoFA, 2022). The coolest month's average temperature is 24°C, while the hottest month's average temperature is roughly 34 °C. It has a relative humidity of between 80% and

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85%. The coastal savannah, which has grassland and few trees, can be found along the coast, while semi-deciduous forests predominate in the inland areas.

Names of study areas (districts and communities) in the Central Region

Two municipalities, Mfantseman, Efutu and three districts, namely Komenda Edina Eguafo Abirem, Abura Asebu Kwamankese, Gomoa West and Cape Coast Metropolitan districts in the Central Region were selected for the fishermen survey. The six districts surveyed were located in Ghana's coastal savannah agro-ecological zone. The fishermen data survey covered eight communities from the Central region, including Winneba, Apam, Anomabu, Abandze, Biriwa, Moree, Elmina and Komenda. The communities were chosen based on their track record of fishing.

Description of Volta Region study areas

To the east of Lake Volta lies the Volta region (longitude 0°37'17.948"E and latitude 6°19'30.069"N), while to the west is the Republic of Togo. The Gulf of Guinea borders it on the south, while the Oti region borders it on the north. In most part of the year, the region experienced temperatures between 21°C and 32°C due to its tropical environment. A 1500 mm of rain falls there each year. Nonetheless, the region's mean annual rainfall in 2022 was 1000 mm (MoFA, 2022). The main vegetation types in the region are moist deciduous forests in the central part and savannah in the northern and southern parts. Anloga district, with Anloga as its capital, was carved out of the Keta municipality in 2018 and inaugurated on 19th February, 2019. Anloga district and Ketu South municipality are located in Coastal Savannah Agro-ecological zones.

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Names of study areas (districts and communities) in the Volta Region

The districts surveyed were Anloga and Ketu South municipalies. Furthermore, ten communities within the two districts (Ketu municipality and Anloga) were covered for the fishermen data, and these included Adina, Amutinu, Gavedzi, Blekusu, Adafienu, Atiteti, Dzita, Whuti, Woe and Tegbi respectively. The study communities were chosen based on their track record of fishing over the years. The map showing the geographical location of the study areas of fishermen in the Western, Central and Volta regions is represented in Figure 3.1

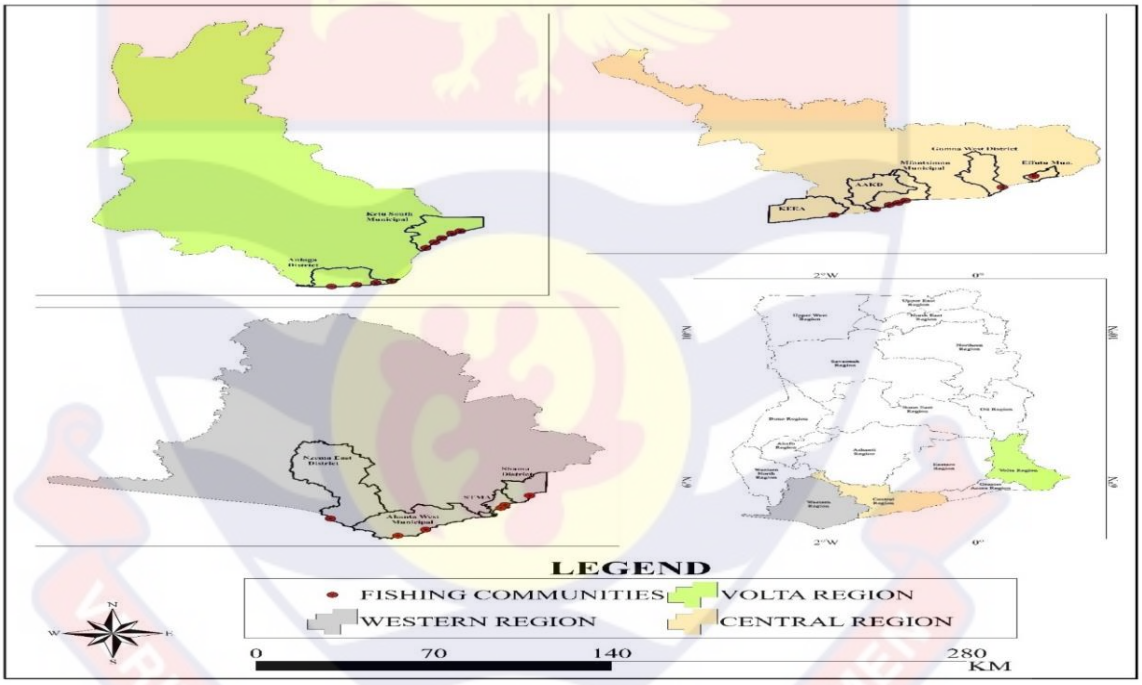


Figure 3.1: Ghana map showing geographical areas of fishing districts/ municipalities/metropolitan district/communities of the Western, Central and Volta regions

The study design

The study used cross-sectional design involving quantitative data collection in surveys of both fishermen and farmers. The cross-sectional design was suitable for this study since information was gathered from households engaged in fishing to shed light on a specific issue. The use of the cross-sectional approach allowed the researcher to

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gather data and assess the changes in the measures of livelihood outcomes of households of fishermen. Furthermore, the cross-sectional design was chosen because there would not be any follow-up after the fieldwork and because of its capacity to deliver quick findings with minimal resources.

The study population

. The study's strata included the district, the municipalities and the metropolis. According to the data from the Ghana Statistical Service 2021 Population and Housing Census, the household population of the study sites was as follows: Household populations in the Central Region included 90,563 in the Efutu district, 125,867 in Gomoa west, 162,284 in Mfantseman municipality, 119,719 in Abura Asebu Kwamankese district, 170,966 in Cape Coast Metropolitan and 160,465 in the Komenda Edina Eguafo Abirem district. In the Western region, there were 114,565 households' population in the Shama district, 233,790 in the Sekondi/Takoradi Metropolis, 151,003 in the Ahanta West district and 92,933 in the Nzema East district. Anloga district's households numbered 92,385 in the Volta region, whereas Ketu South municipality had a household population of 250,499.

Sampling procedures and sample size

A sample is a subset of the population (collection of individuals, objects or items) chosen for a study to represent the population under consideration for accurate research. However, sampling selects the target population units that will be included in the study (Sarantakos, 1997). A well-known fisherman was chosen as the first respondent in a chain referral sampling technique. They then offered another well-known respondent and so on, until the village's or town's expected number of respondents was reached. When using this sampling strategy, the researcher did not pass up a worthwhile respondent.

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Determination of sample size using Krejcie and Morgan's (1970) sampling formula

The sample size for the current study was determined using the Krejcie & Morgan (1970) sampling technique as in Equation [3.1] below:

Sample size estimate $(S) = X^2NP(1-P) + d^2(N-1) + X^2P(1-P)$ …… [3.1]

Where:

S = Required sample size

X^2 =The table value of chi-square for a degree of freedom-it's the desired confidence level (3.841)

N = the population size

P = the population proportion (assumed to be 0.50 since this will provide the maximum sample size)

d = the degree of accuracy expressed as a proportion (0.50).

Therefore, a total of 280 fishermen were sampled from the total population in 5 communities each in the Anloga district and in Ketu South municipality in the Volta Region, 256 fishermen were sampled from the total population in 8 communities in the Efutu, Gomoa West, Mfantseman, Abura Asebu Kwamankese, and Komenda Edina Eguafo Abirem districts in the Central Region and 246 fishermen sampled from 6 communities in Shama, Secondi/Takoradi, Ahanta West and Nzema East in the Western region were necessary sample size for representation of the survey. Seven Hundred and eighty-two (782) fishermen were sampled from the Western, Central and Volta regions.

Test for validity and reliability of data collection instruments

Internationally recognized research standards were used to ensure the study had external validity, allowing the results to be applied to different contexts. In the three regions where farming and fishing were the main economic activities, a pre-survey was

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undertaken with the chief fishermen, regional and district directors of agriculture and others, including local interpreters.

The relevant literature on the study topics was read to ensure that the information in the research instrument covered all the study's objectives. In a logically organized manner, simple terms were utilized to assure the accuracy of the instruments. The research instrument underwent pre-testing or pilot study, on a small number of homes in chosen localities within the three regions. The data from the pilot study were used to compute Cronbach's alpha and it was determined that the value (0.77) was sufficient to ensure the dependability of the data-gathering tool. During the fieldwork, the correct processes were followed and some flaws, inadequacies, ambiguities and issues with the sampling methodologies and data collection methods discovered during the pilot project were corrected.

Recruitment and training of field assistants

Seven field assistants were hired and trained to administer questionnaires and gather data for this exercise. The researcher joined these people to interview farmers and fishermen in the Volta, Central and Western regions of Ghana. The field assistants hired possessed University degrees, a basic understanding of research, and a fair command of English and the local dialects in the selected communities. These characteristics allowed them to clarify the questionnaires for respondents with questions. The field assistants were taught a fundamental understanding of the variables under research to ensure that the data quality was not compromised. Additionally, they received training on administering questionnaires effectively and on moral concerns with data gathering.

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Data collection procedures

Before data gathering from respondents, a permit was sought by the researcher from the Ministries of Food and Agriculture, Fisheries and Aquaculture, for approval from the leaders of these organizations to administer questionnaires to crop farmers, and fishermen. A comparable authorization was requested from the farm manager to enable the agronomic trials at the UCC School of Agriculture's Alexander G. Carson Technology Village. A meeting was conducted to explain the study's goals and the questionnaire to each site's chief fisherman, agricultural extension agents and opinion leaders.

Sources and data collection

Interviews with the respondents provided the primary data. Field notes were kept due to observations made in the field and casual conversations with certain important figures and opinion leaders in the study areas. The socioeconomic parameters that were obtained were age, sex, occupation, educational level, marital status, family income, size of family and the perception of *Sargassum*, beaching, management, and socioeconomic relevance among coastal dwellers and fishermen.

Ethical issues

First, in order to ensure ethical behavior in the conduct of this research, an application for ethical clearance from the University of Cape Coast Institutional Review Board (UCC-IRB) was made on April 6, 2022, and it was granted on October 11, 2022 (see appendix A). Permission was also sought from the respondents to administer the questionnaires. Two weeks before the delivery of the questionnaire, consent forms obtained from UCC-IRB were distributed. Additionally, participants in the study were made aware of their clear rights, safeguards and the voluntary nature of their involvement. Secondly, the respondents were informed about the objectives and

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procedures regarding the study, as well as the fact that their participation would protect them from physical harm. Participants were also informed of the study's confidentiality, which would prevent names from being revealed in the research report and ensure that the data submitted would only be utilized for academic purposes.

Data processing and analysis

Before analysis, the quantitative data were cleaned, edited, coded and modified. All the quantitative data were captured first in Excel. It was later on copied onto SPSS. The data were finally analysed using IBM-SPSS STATISTICS version 22. Summary tables were created using descriptive statistics (frequencies, averages, percentages, standard deviations, minimum, maximum and cross-tabulations). The management levels, socio-economic issues based on areas and knowledge levels of respondents were compared using analysis of variance (ANOVA) and chi-square ($\varkappa^2$). Friedman's ranking test was used to rank *Sargassum*'s economic, aesthetic tourism and ecological problems posed to coastal dwellers and fishermen. Additionally, multiple linear regression analysis using the ordinary least square approach (OLS) to quantify the effects of socio-demographic indicators (age, level of education, family income and family size) on the effects of knowledge and management, economic, tourism and ecological concerns was undertaken. Pearson product-moment correlation coefficient analysis was employed to determine the association between age, educational attainment and *Sargassum* knowledge and management.

The chi-square statistic is calculated as:

$$\chi 2 = \Sigma [(observed\ frequency - expected\ frequency)\ ^2 / expected\ frequency] \quad [3.2]$$

Where:

- $\chi 2$ = *chi-square statistic*

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- observed frequency = number of observations in each category

- expected frequency = number of observations expected in each category under a null hypothesis

The degrees of freedom (df) are calculated as:

Df = (number of rows – 1) x (number of columns – 1)

The Friedman test is based on the following formula:

$\chi^2 = (12/mk(k+1)) * \Sigma Ri^2 – (3m(k+1))$ ---------- [3.3]

Where:

- χ^2 = Friedman's chi-squared statistic

- m = number of judges or evaluators

- k = number of items or objects being evaluated

- Ri = sum of the ranks for the i-th item

- ΣRi^2 = sum of the squared sums of ranks for all items

Results

Socio-economic characteristics of fishermen

Gender and age of fishermen

All the fishermen interviewed were men The highest frequency was 241, representing 30.8% of the fishermen between 40 and 49 years of age. In the meantime, the fishermen's average mean age was 45.1 years, with a minimum and a maximum age of 15 and 80, respectively (Table 3.1).

Table 3.1: Age of Fishermen in Western, Central and Volta regions of Ghana

Characteristics	Frequency	Percentages (%)
<20	3	4
20-29	85	10.9
30-39	175	22.4
40-49	241	30.8
50-59	178	22.8
60-69	90	11.5
70-79	7	0.9
80-89	3	0.3
Total	782	100

Variable	N	Minimum	Maximum	Mean	StD
Age	782	15,00	80.00	45.0883	11.16019

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Regional cross-tabulation of ages of fishermen

Significant difference ($\chi^2 = 53.02$, P <0.001) existed among the mean ages of the fishermen across the Western, Central and Volta regions of Ghana (Table 3.2). In the Central region, 67 fishermen aged between 40 and 49 and 74 fishermen aged between 50 and 59 years. In the Western Region, 91 fishermen were aged between 40 and 49 years. In contrast, 57 were aged between 50 and 59 (Table 3.2). In the Volta Region, 83 fishermen aged between 40-49 years and 47 between 50-59 years. Therefore, between the active years of 40-59, fishermen in the Western region (148) obtained the highest number. This was followed by the Central region (141 fishermen) and the Volta region (130 fishermen) (Table 3.2).

Table 3.2: Regional cross-tabulation of ages of fishermen

Region	<20	20-29	30-39	40-49	50-59	60-9	70-79	80-89	Total
Central	2	21	49	67	74	38	4	1	256
Western	1	13	58	91	57	21	3	2	246
Volta	0	51	68	83	47	31	0	0	280
Total	3	85	175	241	178	90	7	2	782

Chi-square significance value

Model Summary	Value	df	Asymptotic Significance(2-sided)
Pearson Chi-Square	53.015[a]	14	.000

Marital status of fishermen

Six hundred and sixty-six (666) (85.2%) of the fishermen were married, 76 (9.7%) of them were divorced and 35 (4.5%) were single (Table 3.3).

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Table 3.3: Marital status of fishermen

Characteristics	Frequency	Percentages
Single	35	4.5
Married	666	85.3
Divorce	76	9.7
Widow/Widower	5	0.5
Total	782	100.0

Educational level of fishermen

In all, 66.6% of the fisherman had never attended school, 9.6% had completed primary school, 8.4% had completed middle school, 7.8% had completed JSS, 7.4% had completed SSS/SHS and 0.1% had completed tertiary education (Table 3.4).

Table 3.4: Educational level of fishermen

Characteristics	**Frequency**	**Percentages (%)**
No formal Education	521	66.6
Primary	75	9.6
JSS	61	7.8
Middle school	66	8.4
SSS	58	7.4
Tertiary	1	0.1
Total	782	100.0

Educational level of fishermen during regional cross-tabulation

Significant differences (χ^2 = 397.57, P<0.001) existed among the mean educational levels of respondents (Table 3.5). In the Central region, 10 fishermen had JSS education, 17 had elementary education and 227 had no formal education. One individual had tertiary education (Table 3.5). In the Western region, 228 had no formal education, while 11 and 7 primary school and JSS education, respectively. In the Volta region, 66 fishermen had no formal education, 47 had primary education, 44 had JSS, 65 had middle school, and 58 had SSS/SHS education (Table 3.5).

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Table 3.5: Educational level of fishermen during regional cross-tabulation

Region	No formal Education	Primary School	JSS	Middle School	SSS/SHS	Tertiary	Total
Central	227	17	10	1	0	1	256
Western	228	11	7	0	0	0	246
Volta	66	47	44	65	58	0	28
Total	521	75	61	61	66	58	782

Chi-square significance value

Summary	**Value**	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	397.567[a]	8	0.000

Family size of fishermen

Four hundred and thirty-four (434) (56.2%) of the fishermen had a family size between 4-6, followed by 27.1% (212) of the fishermen having a family size of 7-9, 10% having a family size between 10-12, 0.6% having a family size of 13-15 and 0.4% fishermen having a family size greater than 15. In general, the minimum family size was 1, and the maximum family size of fishermen was 19, with an average mean family size of 6.47 (Table 3.6).

Table 3.6: Family size of fishermen

Characteristics	Frequency	Percentage
1-3	41	5.3
4-6	434	56.2
7-9	212	27.5
10-12	77	10.0
13-15	5	0.6
>15	3	0.4
Total	772	100

Variable	**Min.**	**Max.**	**Mean**	**StDev.**
Family size	1	19	6.47	2.830

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Regional cross-tabulation of family size of fishermen

Significant differences (χ^2 = 90.49, P<0.001) were found in the family sizes of fishermen (Table 3.7). In the Central region, ten fishermen had a family size between 1-3, 98 fishermen had a family size between 4-6, 91 fishermen had a family size between 7-9, 45 fishermen had a family size between 10-12, 4 fishermen had a family size between 13-15 and 2 fishermen had a family size greater than 15 (Table 3.7). In the Western region, eight fishermen had a family size between 1-3, while 137 fishermen had a family size between 4-6. While 79 fishermen had a family size between 7-9, 20 people had a family size between 10-12. One person each had a family size between 13-15 and greater than 15 family size, respectively. However, in the Volta region, 23 had a family size between 1-3, 199 fishermen had a family size of 4-6, 42 fishermen had a family size of 7-9, 12 fishermen had a family size between 10-12 and 1 person had a family size greater than 15 (Table 3.7). The greater proportion of fishermen had a family size between 4-6 in the three regions. Fishermen in Volta appeared best in terms of population (199 fishermen), followed by 137 fishermen in the Western and 98 fishermen in the Central region (Table 3.7).

Table 3.7: Regional cross-tabulation of family size of fishermen

			Family	Size			
Region	1-3	4-6	7-9	10-12	13-15	>15	Total
Central	10	98	91	45	4	2	250
Western	8	137	79	20	1	1	246
Volta	23	199	42	12	0	1	277
Total	41	434	212	77	5	4	773

Chi-Square Tests	**Value**	**df**	**Asymptotic Significance (2-sided)**
Pearson Chi-Square	90.493[a]	10	0.000

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Annual income of fishermen

Results in Table 3.8 showed the annual income levels of the fishermen. The majority of the fishermen's (265) income from fishing ranged between GH₵ 100 and GH₵ 1001 per year with a percentage of 33.9% and 29.4% (230) earning an income between GH₵ 1001 and GH₵ 2000. At the same time, one hundred and twelve (112) fishermen, representing 14.3% earned an income between GH₵2001-GH₵3000, forty-two (42) fishermen, representing 5.4% earned an annual income between GH₵ 3001-GH₵4000. Only 0.5% of the fishermen earned an annual income greater than GH₵ 10000. However, the minimum income earned by fishermen was GH₵ 100, while the maximum income was GH₵30,000 a year (Table 3.8).

Table 3.8: Annual income of fishermen

Characteristics	Frequency	Percentage
<1001	265	33.9
1001-2000	230	29.4
2001-3000	112	14.3
3001-4000	42	5.4
4001-5000	31	4.0
5001-6000	6	0.8
6001-7000	4	0.5
7001-8000	4	0.5
8001-9000	3	0.4
9001-10000	32	4.4
>10000	4	0.5
Total	733	100

Variable	Min.	Max.	Mean	St dev.
Income	100.00	30000.00	2408.70	2654.69

Annual income of fishermen during regional cross-tabulation

Significant differences (χ^2 = 90.49, P < 0.001) existed in the annual income from fishing earned by the fishermen in the three regions (Table 3.9). Most of the fishermen in the three regions earned annual income below GH₵ 1001, followed by those who earned annual income between GH₵1001-2000 and GH₵ 2001-3000

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totalling 265 fishermen, 230 fishermen and 112 fishermen, respectively. Within these brackets of income, The Volta region had the highest population (125 fishermen), followed by the Western region (110 fishermen) and the Central region (30 fishermen) earning an annual income of below GH₵ 1001 (Table 3.9). Again, the fishermen population was highest in the Volta region (117), followed by the Western region (57 fishermen) and Central region (56 fishermen) earning an income between GH₵ 1001-GH₵2000 (Table 3.9).

Table 3.9: Income Range of respondents (cross-tabulation) in the regions

Region	<1001	1001-2000	2001-3000	3001-4000	4001-5000	5001-6000	6001-7000	7001-8000	8001-9000	9001-10000	>10000	Total
Central	30	56	49	30	18	2	3	2	0	24	3	217
Western	110	57	25	12	13	4	1	2	3	8	1	236
Volta	125	117	38	0	0	0	0	0	0	0	0	280
Total	265	230	112	42	31	6	4	4	3	32	4	733

Chi-Square Tests

Model summary	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	189.253[a]	20	0.000

Last time fishermen saw *Sargassum* spp. appeared on their coast

Significant differences (χ^2 = 732.434, P <0.001) existed in the last time fishermen saw *Sargassum* spp appearing on their sea coast (Table 3.10). In the Central region, 200 fishermen reported seeing the *Sargassum* spp. on their coast in March, 2022, while 20 reported seeing the *Sargassum* in May. 2021. In the Western region, 123 fishermen mentioned that they saw the *Sargassum* spp. on their coast in October, 2021, while 116 reported seeing them in March, 2022. In the Volta region, the majority of the fishermen (107) saw the seaweed in July, 2021, while 56 of them also saw it in March, 2022 (Table 3.10).

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Table 3.10: Last time Sargassum spp. appeared on your Coast

Region	Jan 22	Feb 22	March 22	April 22	May 21	Aug 21	Sept 21	Oct 21	Nov 21	Dec 21	Jul 21	Jun 21	Total
Central	7	12	200	11	20	3	0	0	2	1	0	0	256
Western	1	5	116	1	0	0	0	123	0	0	0	0	246
Volta	0	0	56	32	31	0	3	0	0	4	107	43	276
Total	8	17	372	44	51	3	3	123	2	5	107	43	778

Chi-square test	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-square	732.434[a]	22	0 .000

Duration of months of *Sargassum* spp appearance on the sea-coast within a year

Significant differences (χ^2 = 433.521, P <0.001) existed in months respondents periodically saw *Sargassum* spp. on their sea coast (Table 3.11). In the Central region, while most fishermen (122) reported January to December as months, they periodically saw the *Sargassum* spp. one hundred reported March to December as months when the seaweeds were mostly seen on their coast. In the Western region, 196 fishermen reported that the *Sargassum* spp. could be seen in any month from January to December, while 46 of them reported that they always see the sea weed docking on their coast from March-December. However, in the Volta region, 239 respondents reported seeing the *Sargassum* between March and December, while 14 reported seeing it between March and September. In all the three regions, 385 fishermen reported seeing the *Sargassum* spp. between March and December while 320 always saw the *Sargassum* spp. between January and December (Table 3.11).

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Table 3.11: Months of *Sargassum* spp appearance on the coast within a year

Region	Jan - Dec	Feb - Dec	Mar - Dec	Apr - Dec	May- Dec	June - Dec	Jul - Dec	Sept - Dec	Oct - Dec	March - Sept	Total
Central	122	16	100	9	4	3	1	1	0	0	256
Western	196	2	46	1	0	0	0	0	1	0	246
Volta	2	0	239	0	18	0	4	3	0	14	280
Total	320	18	385	10	22	3	5	4	1	14	782

Chi-square test	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	433.521	18	0.000

Fishermen's knowledge of *Sargassum* in coastal communities

Fishermen scored 53% for low knowledge, 23.9% for moderate knowledge, and 22.3% for high knowledge on the kind of weeds they had seen docking on the sea coast (Table 3.12). The fishermen managed 99.4% for high knowledge of the *Sargassum* spp. while scoring 0.6% for low knowledge of *Sargassum* spp. Regarding the colour of *Sargassum*, the fishermen scored 38.8% for low knowledge, 0.9% for moderate knowledge, 33.0% for high knowledge and 27.3% for very high knowledge. The fishermen scored 2.6% for very high knowledge regarding texture and 97.4% for high knowledge (Table 3.12). Furthermore, they scored 46.2% on low knowledge of *Sargassum* and 53.8% on high knowledge of *Sargassum*. The fishermen scored 100% for low knowledge for the quantity of *Sargassum* washed ashore and 100% high knowledge for the quantity in a kilogramme of *Sargassum* that was washed ashore. Regarding the volume of *Sargassum* that occupied their nets, the respondents scored 71.4% for low knowledge and 28.6% for high knowledge (Table 3.12).

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Table 3.12: Fishermen's knowledge of *Sargassum* in coastal communities

Knowledge Statement	Low (%)	Moderate (%)	High (%)	Very high (%)	Total
Type of weeds docking	53.8	23.9	-	22.3	100.0
Knowledge on Sargassum	0.6	-	99.4	-	100.0
Knowledge on colour	38.8	0.9	33.0	27.3	100.0
Knowledge on texture	2.6	-	97.4	-	100.0
Knowledge on structure	46.2	-	53.8	-	100.0
Knowledge on quantity	100.0	-	-	-	100.0
Quantity in terms of kg		-	100.0	-	100.0
Volumes that occupy the net	71.4	-	28.6	-	100.0

Low knowledge=low, moderate knowledge=moderate, High knowledge =High, very high knowledge = Very High.

Management of *Sargassum* spp. after docking on sea coast

When *Sargassum* spp. docked on the coast, fishermen scored 0.3% on low management practices, while 99.7% scored high management practices (Table 3.13). After coming for them, all fishermen scored low management practices of 100% about what people would use the *Sargassum* spp. for. Furthermore, fishermen scored low management practice (98.8%) when leaving *Sargassum* spp. on the coast to rot when no vehicle or people came to gather them away. In comparison, fishermen scored 1.2% on high management practices (Table 3.13). Whether the rotting *Sargassum* spp hinders their fishing activity, the fishermen scored 95.3% on high management practices and 4.7% on low management practices. Additionally, the fishermen scored 38.7% as low management practices, 17.4% as moderate management practices, 7.8% as a high management practice, 15.4% as a very high management practice and 20.0% as excellent management practice on how the rotting of *Sargassum* spp. hinders their fishing activities (Table 3.13). Meanwhile, the fishermen scored 45.3% as low management practice and 54.7% as high management practice on finding uses for the rotting *Sargassum* spp. The fishermen, however, scored, 98.3% as a high management practice and 1.7% as a very high management practice on what the *Sargassum* spp can

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be used for (Table 3.13). Fishermen scored 96.8% as a low management practice and 3.2% as a high management practice on knowledge of *Sargassum* spp. being processed into compost (Table 3.13). In addition, fishermen scored 95.6% as a high management practice and 4.4% as a low management practice on preference of being assisted to make *Sargassum*-based compost (Table 3.13).

Table 3.13: Management of Sargassum after docking on sea coast

Management statement	Low (%)	Moderate (%)	High (%)	Very High (%)	Excellent (%)	Total
Do people or vehicles come for the *Sargassum* as it docks	0.3	-	99.7	-	-	100.0
If yes, what do you think they will use them for?	100.0	-	-	-	-	100.0
If no, do you leave the *Sargassum* to rot?	98.8	-	1.2	-	-	100.0
Does it hinder your fishing activities if it starts rotting?	4.7	-	95.3	-	-	100.0
If yes, how does it hinder your fishing activities?	38.7	17.4	7.8	15.4	20.7	100.0
Is it better, to find uses for the docked *Sargassum*?	45.3	-	54.7	-	-	100.0
If yes, what do you think it will be used for?		-	98.3	1.7	-	100.0
Do you know it can be processed into *Sargassum*-based compost?	96.8	-	3.2	-	-	100.0
If yes, do you know the compost will serve as income for you?	90.5	-	9.5	-	-	100.0
Will you accept assistance in managing the coastal weed?	4.4	-	95.6	-	-	100.0

Low management =low Moderate mgt =moderate, High mgt=High Very high mgt=Very high, Excellent mgt=excellent

Multiple regression analysis of factors influencing *Sargassum* management in the three regions of Ghana

The result of eight independent variables (age, education, marital status, family income, family size, economic problems, tourism problems and ecological problems) influencing the management of *Sargassum* spp. in the three regions was presented in

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Table 3.14. Only one (economic problems) of the eight variables entered had a significant influence on fishermen' attitudes at P<0.01. It also had the largest beta coefficient variable (-.133) which is the strongest unique explanation for the dependent variable (management of *Sargassum* spp.) (Table 3.14). With a beta value of 088, the second closest variable (married status) also indicated a statistically significant differences (P<0.05), significantly influencing the prediction of *Sargassum* species management (Pallant, 2005). The rest of the variables had alpha levels more than 0.05 (P>0.05) implying those factors were not making meaningful contribution to how the dependent variables are predicted. All the variables together explained only (R^2 .032) 3.2 % of the variance in fishermen's attitude to managing *Sargassum* spp well (Table 3.14).

Table 3.14: Multiple regression analysis of factors influencing the management of *Sargassum* in the three regions of Ghana

Variable	Unstandardized Coefficients B	Stand Error	Standardized Coefficients Beta	t-value	P-value
(Constant)	1.817	.120		15.151	.000
Knowledge on *Sargassum*	-.060	.046	-.048	-1.306	.192
Age	-3.422E-5	.001	-.002	-.048	.962
The level of education	.007	.006	.048	1.231	.219
Marital status	.044	.019	.088	2.290	.022
Family income from fishing per year	3.505E-6	.000	.049	1.309	.191
Family size	.003	.003	.039	.922	.357
Economic problems	-.088	.025	-.133	-3.496	.001
Tourism problem	.010	.014	.027	.706	.480
Ecological problem	-.020	.012	-.063	-1.657	.098
Model Summary					
R	.179[a]				
R Square	.032				
Adjusted R Square	.020				
Std. Error of the Estimate	.18684				

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Relationship between management, age, education and knowledge of *Sargassum*

The correlation coefficient was used to examine the association between respondents' age and educational level, as well as their knowledge and management of *Sargassum* spp. To make sure the assumptions of homoscedasticity, linearity, and normality were not broken, a preliminary study was carried out. The knowledge of *Sargassum* and educational attainment had a considerable negative correlation (r = -0.179, n=782, P<0.001) (Table 3.15). The rest of the variable (Management of *Sargassum* spp. r = -0.052, n=782, P>0.05 and age r=0.038, n=782, P > 0.05) did not significantly relate to management of *Sargassum* spp. (Table 3.15). The correlation value is squared, or multiplied by itself, to get the coefficient of determination. Thus, the relationship between fishermen's educational level and their knowledge of *Sargassum* spp. is r = -0.1792, which translates to r = 0.032041, or 3.2% shared variance. Thus, the knowledge of *Sargassum* spp. contributed to the explanation of 3.2% of the variation in the respondents' educational levels.

Table 3.0.15: Relationship between management, age, education and knowledge of *Sargassum*

	Knowledge sargassum	**Management of Sargassum**	**Age**	**The level of education**
Knowledge on Sargassum	1			
Pearson correlation				
significant value				
Management of Sargassum		1		
Pearson Correlation	-0.052			
Significant value	0.145			
Age	0.038	0.038	1	
Pearson Correlation	0.292	0.289		
Significant value				
The level of education				1
Pearson Correlation	0.020	0.049	-0.179**	
Significant value	0.570	0.173	0.000	

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Friedman ranking test of factors leading to economic problems

The chi-square indicated significant (χ^2 = 1946.72, P < 0.001) differences among the factors leading to economic problems (Table 3.16). During the regional cross-tabulation, the mean rank of *Sargassum* spp. clogging the fishing nets of respondents (3.18) was the most common problem encountered by fishermen hence ranked 1st (Table 3.16). This was followed closely by the *Sargassum* tearing the net of fishermen (3.00), and hence ranked 2nd. The inability of the *Sargassum* to capsize the fishing trawlers was the least problem encountered by fisherfolks, with a mean rank of 1.18, hence, it was ranked 4th.

Table 3.16: Friedman ranking test of factors leading to economic problem

Variable	Mean Rank	Standard deviation	Ranking
Does the *Sargassum* clog your fishing net?	3.10	0.00	1st
When it clogs the net, does it tear the net?	3.00	0.00	2nd
Does the *Sargassum* also entangle engine propellers?	2.82	0.29	3rd
Does it cause your fishing boat to capsize?	1.18	0.29	4th
Test Statistics			
N	782		
Chi-Square	1946.73		
Df	3		
Asymp. Sig.	0.000		

Friedman ranking test of tourism, aesthetic and health problems

The chi-square, (χ^2 = 241.203, P<0.001) indicated significant differences among the factors leading to tourism, aesthetic and health problems (Table 3.17). In the regional cross tabulation, most fishermen responded that rotting *Sargassum* spp, irritating their eyes and skin, and respiratory difficulty were pressing problems. They were ranked 1st with a mean score of 2.14 (Table 3.17). This was followed by *Sargassum* spp. causing beach fouling to rank 2nd with a mean score of 2.08 and *Sargassum* spp.

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causing risk fatality of inhaling low concentration of the toxic gas being ranked 3rd with a mean score of 1.78 (Table 3.17).

Table 3.17: Friedman ranking test on tourism, aesthetics and health problem

Variable	Mean Rank	Standard deviation	Ranking
Does the *Sargassum* cause beach fouling and reduces access to the sea and shoreline during swimming and other activities?	2.08	.25816	2nd
Does inhaling highly toxic hydrogen sulphide irritate the skin, eyes and respiratory system?	2.14	.17270	1st
Does it cause a risk of fatality in inhaling low concentrations of the toxic gas?	1.78	.44366	3rd
Test Statistics			
N	782		
Chi-Square	241.20		
Df	2		
Asymp. Sig.	0.000		

Friedman ranking test on factors leading to ecological problems

The chi-square, (χ^2 =33.747, P<0.001) indicated significant differences among the factors leading to ecological problems (Table 3.18). In the regional cross tabulation, most fishermen responded that rotting *Sargassum* spp. caused a change in the normal state of the sea and that the relocation of the marine species. They ranked 1st with a mean score of 2.08. The closest problem was the *Sargassum* spp. causing beach erosion leading to depletion and shoreline instability ranking 2nd with a mean score of 1.98. Furthermore, restricting sea turtles to their nesting locations and creating barriers to the sea for hatcheries was also the least ecologically problematic practice, ranking third with a mean score of 1.94 (Table 3.18).

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Table 3.18: Friedman ranking test on factors leading to ecological problems

Variable	Mean Rank	Standard deviation	Ranking
Does the *Sargassum* spp. cause perturbation (change in normal state) and relocation of marine species?	2.08	.39417	1st
Does it cause beach erosion when it removes sand, leading to depletion and possible shoreline instability?	1.98	.43887	2nd
Does it restrict sea turtles to nesting sites and form a barrier for the hatcheries?	1.94	.45196	3rd
Test Statistics			
N	781		
Chi-Square	33.75		
Df	2		
Asymp. Sig.	0.000		

Economic problems faced by fishermen across the regions

Significant differences (χ^2=196.882, P<0.001) existed in the economic problems faced by fishermen in the three regions (Table 3.19). In the Central region, 144 fishermen reported dwindled fish catch, resulting in low income and 35 people reported fish nets being destroyed badly. Furthermore, 28 fishermen reported their inability to pay their children's school fees and 12 said they could not buy premix fuel regularly (Table 3.19). In Western region, 219 fishermen reported dwindled fish catch and low income, 5 of them reported that faulty engine propellers consumed more fuel, 3 of them said women in fish mongering no longer got jobs to do, and 3 of them said economic hardship was paramount (Table 3.19). However, in the Volta region the entire population reported dwindling fish catch and low income.

Other general problems fishermen faced caused by *Sargassum* spp

Significant differences (χ^2 = 111.596, P < 0.001) existed in the general socio-economic problems faced by fishermen in the three regions. In the Central region, 86 fishermen reported that the *Sargassum* spp. made their work difficult and less profitable. In contrast, 47 reported that once the *Sargassum* spp. remained in the deep sea, they suspended their fishing activities. In addition, 43 fishermen said that the

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Sargassum increased their production costs, leading to lower incomes (Table 3.20). In the Western region, 21 fishermen reported that the docked *Sargassum* spp. prevented their trawlers from being pulled ashore and 33 reported that it negatively affected tourism, fisheries, shoreline activities and biodiversity (Table 3.20). While 70 of the fishermen reported that, the seaweed increased their cost of production, 27 of them reported that the sea weed seized their net at night fishing and they were forced to throw the net into the sea to prevent their boat from capsizing. In the Volta region, 101 respondents lamented that the seaweed made their work difficult and less profitable. Additionally, while 67 of them reported that the seaweed increased their cost of production, only 2 of them said the seaweed stopped their boat at night and sometimes produced cracks on them (Table 3.20).

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Table 3.19: Economic problems faced by fishermen across the region

Region	Dwindled fish catch &low income	Engine propellers are destroyed	Faulty propellers consume more fuel	Fishmongers are out of business	Fish nets are destroyed badly	Economic hardship is paramount	Children's school fees cannot be paid	We cannot buy premix fuel regularly	Total
Central	144	10	4	9	35	14	28	2	256
Western	219	0	5	3	8	4	3	4	246
Volta	280	0	0	0	0	0	0	0	280
Total	643	10	9	12	43	18	30	16	782

Chi-Square Texts	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	196.882[a]	14	0.000

Table 3.0.20: Other general problems fishermen faced caused by *Sargassum* spp.

Region	Docked Sargassum prevents boats from being pulled ashore	We suspend fishing activities once they remain in the sea	It increases the cost of production hence less income	The entangled nets are abandoned for at least seven days to soften Sargassum	It seizes our net and we are forced to throw it into the sea	lt makes our work more difficult and less profitable	They impact negatively on tourism, fisheries, shoreline activities &biodiversity	It stops our boats from moving at night and produces cracks in them	Total
Central	15	47	43	12	11	86	31	11	256
Western	21	22	70	28	27	36	33	9	246
Volta	26	50	67	28	4	101	2	2	280
Total	62	119	180	68	42	223	65	22	782

Chi-Square tests	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	111.596[a]	14	0.000

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Discussion

Background characteristics of respondents

The fact that most fishermen were men may be attributed to the physical demands of fishing, supporting the findings of FAO (2022), which stated that 80% of the nation's fishermen were employed in the artisanal or small-scale fisheries sector; women, however, are essential to this industry because they preserve, process and market fish.

A robust workforce for fishing was indicated by the fishermen's relatively young ages. Additionally, the majority of fishermen will be able to support their husbands in the areas of fish preservation, processing and marketing if they get married. This is consistent with the conclusions drawn by the World Bank (2012) and Bennet (2005) that, women are essential to the fisheries industry because they provide services like financing the fleet, processing and marketing the catch.

Sixty-six percent of the respondents had no formal schooling implying that fishermen falling into these categories must rely on their experience rather than their intellectual capacity to solve the complicated challenges posed by the mats of *Sargassum* spp. at sea. Fishermen's poor educational attainment would also make them more susceptible and limit their access to information on contemporary fishing outside of what they learn from their immediate surroundings. A smaller family would make it easier for the home to make plans and increase the money to cover their expenses.

Fishermen earned low income from fishing annually. The reason may be the dwindling fish catch due to the abundance of *Sargassum* spp. occupying every part of the sea, bringing economic hardships and reducing livelihoods for fishermen.

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Last time fishermen saw *Sargassum* spp. on their coast

There was a significant difference in the last times (months) the fishermen saw *Sargassum* spp. on their coast. This showed that the fishermen had adequate knowledge about the beaching of *Sargassum* spp. in their respective coastal waters. Since 2011 there had been widespread of *Sargassum* spp. abundance in the Atlantic Ocean and has affected resources of the marine, ecosystems, beaches, Caribbean communities and West Africa (Hinds *et al.,* 2016; Kershaw, 2017; Franks *et al.,* 2016, Wang *et al*., 2019; Oxenford *et al.,* 2021). This had emerged as a major concern for the Caribbean. The null hypothesis that stated that coastal communities had limited knowledge of the beaching of *Sargassum* is rejected and the alternative hypothesis is accepted.

Duration of months of *Sargassum* spp. appearance within a year

The months that *Sargassum* appeared along the seashore varied significantly. When *Sargassum* spp. were observed beaching on their coast between March and December and between January and December, the majority of fishermen identified the *Sargassum*. The results align with the reports from UNEP-CEP (2021) and Asiedu *et al.* (2022) that *Sargassum* spp. primarily occurred in the rainy season which is May and August in the South-Western region of Nigeria's coast and that the *Sargassum* spp. invaded coastal marine waters, beaches and lagoons around April, May and June before completely disappearing during the major rainy season.

Knowledge of fishermen about *Sargassum* spp. docking on the coast

Knowledge of the kinds of weeds respondents were familiar with and which they saw beaching on their coast ranged from low to very high (ie green weeds, floating weeds, yellow weeds, brown weeds and *Sargassum*, respectively). This indicated that fishermen's responses in the three regions differed in the kind of weeds they had seen beaching on their coast.

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The knowledge of colour (green/yellow, yellow, yellow/black, brown and brown/black) varied from extremely low to very high. This is in line with Doyles & Franks (2015) who described pelagic *Sargassum* as a golden-brown seaweed that floats freely in the Atlantic Ocean. The three regions' respective levels of knowledge regarding the texture of *Sargassum* spp. varied significantly. The knowledge was smooth, soft, light and gentle, ranging from low to high. The null hypothesis is rejected that states that coastal communities in the regions have limited knowledge in the texture of *Sargassum* spp. and the alternative hypothesis is accepted.

The three regions' respective *Sargassum* spp. structures differed significantly from one another as reported by the fishermen. Their knowledge ranged from low to high (many leaves, few leaves and short stem). The null hypothesis is rejected and the alternative accepted.

Management of *Sargassum* after docking on the sea coast

People did not go looking for *Sargassum* spp. when they wash ashore because in Ghana, they are regarded as waste, which is different from what had been seen in places like the Caribbean, where *Sargassum* is also highly prevalent in the tourism, fishing and sports sectors (Robledo *et al.*, 2021; UNEP-CEP, 2021).

In some coastal communities, for example in the Central region, fishermen leave the *Sargassum* to rot on the beaches. The decomposing *Sargassum* gave vile smell and in the process, caused a lot of discomfort to the fishermen such as itching their feet, breathing difficulty and in many cases, making some fishermen sick and vomiting frequently. In the Volta region, in their desperate attempt to get rid of the seaweed, the fishermen tried to dig a big hole and bury the seaweed in it. At the same time, they forgot that such a method would change sand's chemical nature, which may not permit the turtles' hatchlings.

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In the Western region, however, the use of the *Sargassum* was discovered recently when Opportunity Industrialization Centre International (OICI), a beach clearing non-governmental organization, undertook a pilot project with the Ministry of Agriculture, Ahanta West district and distributed 50kg of *Sargassum* spp. to many of the farmers to try it on their farms. Some farmers burn their crops because of the heat from the decomposing *Sargassum* spp. (Personal Communication, George Dogbetor, Program Head, OICI, 2023). This study conflicts with those of Abdool-Ghany *et al.* (2023) who reported that the management of seaweed in Southeast Florida provided a novel strategy by evaluating the economics of *Sargassum* composting as a means of managing seaweed trash on beaches. The null hypothesis is accepted, which states that coastal communities in the regions have limited knowledge of managing *Sargassum* spp.

Multiple regression analysis of factors influencing *Sargassum* management in Ghana's three regions

From the regression analysis results where management was the dependent variable, fishermen faced economic problems from *Sargassum* both at sea and on land. Therefore, they could not clear the beaches, let alone transformed the *Sargassum* spp. into a useful product such as compost. This also means that the more money fishermen had the more they will use it to clear the beach or transform the *Sargassum* into compost to benefit the agricultural sector. These findings agree with Abdool-Ghany *et al.* (2023), who reported that money for clearing beaches in Southeast Florida could be more expensive than *Sargassum* composting. The null hypothesis is, therefore, rejected in favour of the alternative that coastal communities in Ghana have adequate knowledge of economic problems, hence, *Sargassum* management is very poor.

Marital status was also significant indicating that marriage could provide additional labour for households. Marriage could bring in more labour, leading to an

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increase in workforce and high production. High production would lead to high income, and high income would lead to high management of *Sargassum* on the coast. Furthermore, those who were married will have their women sponsoring them to buy fishing boats, nets, and premix fuel compared to those who were single. This study is consistent with research demonstrating that women contribute significantly to the fishing sector both before and after the harvest by processing and selling the fish captured (World Bank, 2012; Bennett, 2005).

Relationship between knowledge, management, age and education level of *Sargassum* spp.

Knowledge of *Sargassum* and the educational level of fishermen were strongly correlated negatively. This is understandable because some level of education is needed to correctly identify the nature, colour, texture and structure of these *Sargassum* spp. The more educated the fishermen were, the more easily they could identify the *Sargassum* spp. and vice versa.

Factors leading to economic problems caused to fishermen by *Sargassum* spp.

The fishermen faced problems at sea which were reported across the region. The fishermen in all three regions agreed that *Sargassum* spp. clogging their nets was the biggest problem they encountered at sea. The *Sargassum* clogs their nets and displaced fish in the net, hence, they catch *Sargassum* spp. instead of fish, leading to dwindling fish catches. Sometimes, when the fishing nets were clogged by *Sargassum* spp. these fishermen abandoned the nets in their trawlers for some days to enable the *Sargassum* to start deteriorating before removing them from the nets. The fishing communities' way of life was impacted by fish densities and abundance of *Sargassum* (Oxenford *et al*., 2021; Hinds *et al*., 2016; CRFM, 2012; Ramlogan *et al*., 2017; JICA & CRFM, 2019). Fishermen from all the three regions (Volta, Central, and Western) also reported that the second problem they encountered at sea was tearing of fishing nets. When the

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fishing nets were torn, they spent more time mending them, hence, delaying their fishing periods. Thirdly, all the fishermen in the three regions reported that the *Sargassum* spp. entangled their engine propeller during the Friedman rank test. According to the fishermen, when these *Sargassum* spp. entangled these engine propellers, it seized their boats from propelling through them. Their engine propellers developed faults afterwards and consumed more fuel. The least ranked problem by the Friedman ranking test was the inability of the *Sargassum* spp. mat at sea to capsize their fishing trawlers. Even though the *Sargassum* spp. worried their fishing trawlers at sea, they could manoeuvre around them using their fishing experience.

Tourism, aesthetic and health problems caused by *Sargassum* spp. to fishermen

The most common health issue mentioned by fishermen in the three regions (Volta, Central and Western) was *Sargassum* spp. irritating skin, eyes and respiratory system after breathing in extremely poisonous hydrogen sulphide gas. The gas from the decomposing *Sargassum,* hydrogen sulphide, made breathing difficult for the fishermen. Hazardous exposure to hydrogen sulphide from *Sargassum* decomposition usually occurs during 48 hours after it is washed ashore (Resiere *et al.* 2023). Higher hydrogen sulphide concentrations immediately resulted in acidosis, unconsciousness, myocardial infarction, seizures and mortality according to Resiere *et al.* (2021) due to *Sargassum* spp. beach fouling, which was the second most often mentioned problem among fisherman. This restricted access to the sea and shoreline for swimming and other activities hindered tourism. Ghana's coastal zone has drawn tourists from overseas and locally for the beach, sun and water since the late 1980s as part of the country's economic growth strategy (Tweneboah *et al.*, 2009). But since the migration was first reported in 2009 and the subsequent mass arrival in 2011, tourism had declined dramatically, costing those who relied on their patronage to exist. Because of the 2015

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massive *Sargassum* spp. inundation of the Gulf of Mexico and the Caribbean, some 10,000 metric tons of fresh seaweed washed up on the coast every day (Milledge & Harvey, 2016). The third most critical hazard facing fishermen was the danger of dying from breathing in a small bit of extremely toxic gas. This study corroborates the findings by ANSES (2017) and Resiere *et al.* (2018) which demonstrated that the breakdown of *Sargassum* spp. produced hazardous gasses and can result in possibly fatal health consequences in people. Additionally, the study supports the findings of Kershaw *et al.* (2017) who stated that there is a risk of death, while breathing in low concentrations of severely dangerous gas.

Ecological problems caused by *Sargassum* spp. to fishermen

Sargassum spp. have a bigger impact on the coast, the communities and near-shore habitats whose livelihoods depend on having access to the coastline, according to Louime *et al.* (2017). Overall, it was seen that the ecosystems were impacted by beach erosion, fish kills, die-offs of coral and seagrass beds and disturbances of turtle nesting sites (Rodriguez-Martinez *et al.*, 2019; van Tussen Broeck *et al.*, 2017; Maurer *et al.*, 2015). Furthermore, when heavy machinery was used to gather *Sargassum*, which caused coastal erosion, a lot of sand was removed from beaches (JICA & CRFM, 2019). According to the Friedman ranking test, fishermen in all the three regions reported that the biggest problems they faced during the *Sargassum* inundation on the coast were "change in normal state and relocation of marine species, followed by removal of sand, causing beach erosion and possibly shoreline instability" and "restrictions on sea turtles' access to nesting sites and forming a barrier to the sea for the hatcheries." This study supports the research findings of Maurer *et al.* (2015) and Kershaw (2017), which showed that turtles seeking to nest were prompted by the environmental bloom of

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Sargassum in China and that *Sargassum* beach landings could impede neonatal hatchlings' ability to survey the sea.

Economic problems faced by fishermen across the regions

In the three regions (Volta, Central and Western regions) the biggest economic problem faced by fishermen was dwindling fish catch and low income. In many instances when they cast their nets, the numerous *Sargassum* spp. occupying the net seized the net from the fishermen and in an attempt to pull the nets, the weight of the *Sargassum* spp. in the net prevented them from doing so. They cut the net into pieces to rescue themselves from being thrown into the sea. When the *Sargassum* flood started, the affected communities were compelled to declare a "no fishing" season to save their investment. Because of the low catches, fish processors, primarily women, were negatively impacted. Since the women were the ones who funded the fishing trip (EFJ, 2022) "no fishing," "no fish," "no money," and "no food" had an impact on everyone, including their families. According to Xing *et al.* (2017) *Sargassum* increased the cost of China's aquaculture sector by $73 million. This result validates earlier studies indicating *Sargassum* spp. jams, fishing gear and reduced fishing areas, lowered revenue and escalated cost of maintenance (Solarin *et al.*, 2014; Ramoglan *et al*., 2017).

Other general problems fishermen faced caused by *Sargassum*

According to Doyle & Franks (2015), *Sargassum* is a crucial nursery habitat that supported endangered species like sea turtles and commercially significant species like tunas by providing food and shelter. May, through September, were known to be the months when *Sargassum* was most common and these were also very important for the travel and tourism sector. *Sargassum* episodes' most catastrophic ecological and economic blooming occurred between 2015 and 2018 (Mendez-Tejeda & Rosado Jimenez, 2019). Cox *et al.* (2019) reported that because of how unexpected the influxes'

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quantity (in terms of time, location and volume) and wide-ranging impact were, research and management were lagging behind. The fishermen's jobs were made difficult and less lucrative since on some occasions, they would work throughout the night to battle *Sargassum* at a deep-sea location and return home empty-handed. Sometimes, the floating *Sargassum* spp. gets entangled in the fishermen net and causes the net to roll up. In addition, the *Sargassum* spp. seized their nets and for fear of their fishing trawler being capsized, they were forced to throw the fishing nets into the sea. Women who worked in the distribution, processing and marketing of fisheries products were impacted when there was a dwindle in the number of fish caught and the length of the fishing season (Adet *et al.*, 2017). The fishermen nicknamed the *Sargassum* 'boys abre' meaning 'boys are tired' because according to them it brings economic hardship, 'Abidjan abre' meaning Abidjan is tired because the *Sargassum* originated from Abidjan and 'Suarez' because it takes away their fish from them.

According to the fishermen, when the *Sargassum* spp. were washed ashore, it prevented their fish trawlers from being pulled ashore or moved into the sea. Their fish trawlers, therefore, remained in the sea and many got rotten, causing financial loss. The results of this study corroborate the findings by many researchers in the literature (Louime *et al*., 2017; Adet *et al*., 2017; Milledge & Harvey, 2016; Franks *et al.*, 2012; Cháv*e*z *et al.*, 2020a). The null hypothesis that coastal communities have limited knowledge of socio-economic problems is rejected in favour of the alternative.

Conclusion

The fishing communities in the Volta, Central and Western regions were completely threatened by *Sargassum* spp. based on interviews and interactions with coastal communities. The density and frequency of *Sargassum* landings were growing, indicating a deterioration of the situation for these populations. The coastal inhabitants

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in the area were appropriately identified. The fishermen could recall the day and month the *Sargassum* spp. arrived at their shore. Furthermore, the coastal communities were sufficiently informed about the nature, colour, texture, structure and socioeconomic problems they faced. However, the coastal communities did not have adequate knowledge of seaweed management, nor did they transform it into compost for agricultural purposes.

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CHAPTER FOUR

FARMERS' PERCEPTION OF ORGANIC MANURE AND SARGASSUM-BASED COMPOST

Introduction

Management of ecosystem, excluding external input, especially inorganic input is essential to organic farming. Anderson *et al.* (2005) defined organic farming as a production plan, excluding the use of artificial fertilizers, growth regulators, pesticides and animal feed additives. Increasing soil nutrient availability, microbial activity, microbial biomass and organic management automatically affects the microbiological and chemical characteristics of the soil (Marinari *et al.*, 2006). Compared to other farming systems, the bacterial biomasses in an organic farming system that perform soil activities and can endure environmental stress are more significant (Mulder *et al.*, 2003). Because locally available organic resources or recycled agricultural wastes assist farmers in maintaining nutrient balances in the soil, organic farming improves ecological health (Park *et al.*, 2008). Furthermore, supporters of organic farming found that plants grown when biological nutrient sources such as manures and composted organic wastes are used may be less susceptible to insect pest destruction than conventionally produced plants (Barna *et al.*, 2015).

Applying organic manure has often resulted in increased yields, which greatly increased the food security of a particular area or region (Park *et al.*, 2008). FAO (2006) stated that using organic sources of materials in agriculture had significantly contributed to transforming the world's impoverished vulnerable land into ecological zones with a high productivity of crops.

Based on reports from earlier researchers, it has been noted that there are differences and disagreements regarding the constraints to farmers using organic

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manure. Wheeler (2008) listed a number of problems that farmers encountered when using organic manure and this includes labour-intensive nature of the product, its slower rate of effectiveness, the scarcity of manure sources, its higher cost, the need to store manure, the growth of weeds and the unpleasant odour of the majority of organic manure. According to Pornpratansombat (2010), there are additional constraints to adopting organic manure such as a lack of technical expertise and skills. Furthermore, the primary constraint to the usage of farm yard manure was determined to be transportation, according to Odhiambo & Magandini (2008). This runs contrary to research conducted in Nigeria by Alimi *et al.* (2006) who reported that, the two main issues farmers had with organic manure use are questionable efficacy and unpleasant odour.

Objective

To assess farmers' perception of organic fertilizer application, constraints of organic manure use and factors leading to acceptance and buying of *Sargassum*-based compost.

Hypotheses

Ho: Farmers are not aware of organic manure and they do not use it.

H_1: Farmers are aware of organic manure and they use it.

Ho: Farmers are not aware of factors preventing them from using organic manure.

H_1: Farmers are aware of factors preventing them from using organic manure.

Ho: Farmers are not aware of constraints of organic manure.

H_1: Farmers are aware of the constraints of organic manure.

Ho: There is no agreement among farmers' rankings of organic manure constraints.

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H_1: There is agreement among farmers' rankings of organic manure constraints.

Ho: Farmers are not aware of the importance of *Sargassum* compost and are not willing to accept, buy and use it.

H_1: Farmers are aware of the importance of *Sargassum* compost and are willing to accept, buy and use it.

Name of study areas municipal, districts and communities

The Western Region

The study areas have been described in chapter 3. The districts were Sekondi/Takoradi Metropolitan district, Ahanta West and Nzema East. Communities included Sekondi, New Takoradi, Takoradi, Ketan, Kwesikrom, Akwidaa, Katakro, Achonwa, Bebianiha, Butre, Akyinim, Brawire, Domunli, Agyan and Akonu.

The Central Region

The districts were Cape Coast metropolitan district and Mfantseman municipality. The communities surveyed were School of Agriculture Teaching and Research farm, University of Cape Coast and the Baifikrom-Mankessim Irrigation Water Users Association.

The Volta Region

The districts were Anloga and Ketu South municipality. Crop producers from thirteen communities in the Anloga district, including Tegbi, Woe, Avume, Agorve, Dornorgbor, Kportorgbi, Atsugbor, Setsinu, Atiehefe, Whuti, Dzita, Atokor and Anyanui were chosen for the study. Additionally, nine communities in the Ketu South municipality were surveyed. These included Adafienu, Hedzranawo, Aflao, Denu, Agortorme, Agbozume, Lashikpodzi, Kpordoave and Glidzi. The map showing the geographical study areas in Western, Central and Volta regions is presented in Figure 4.1 below:

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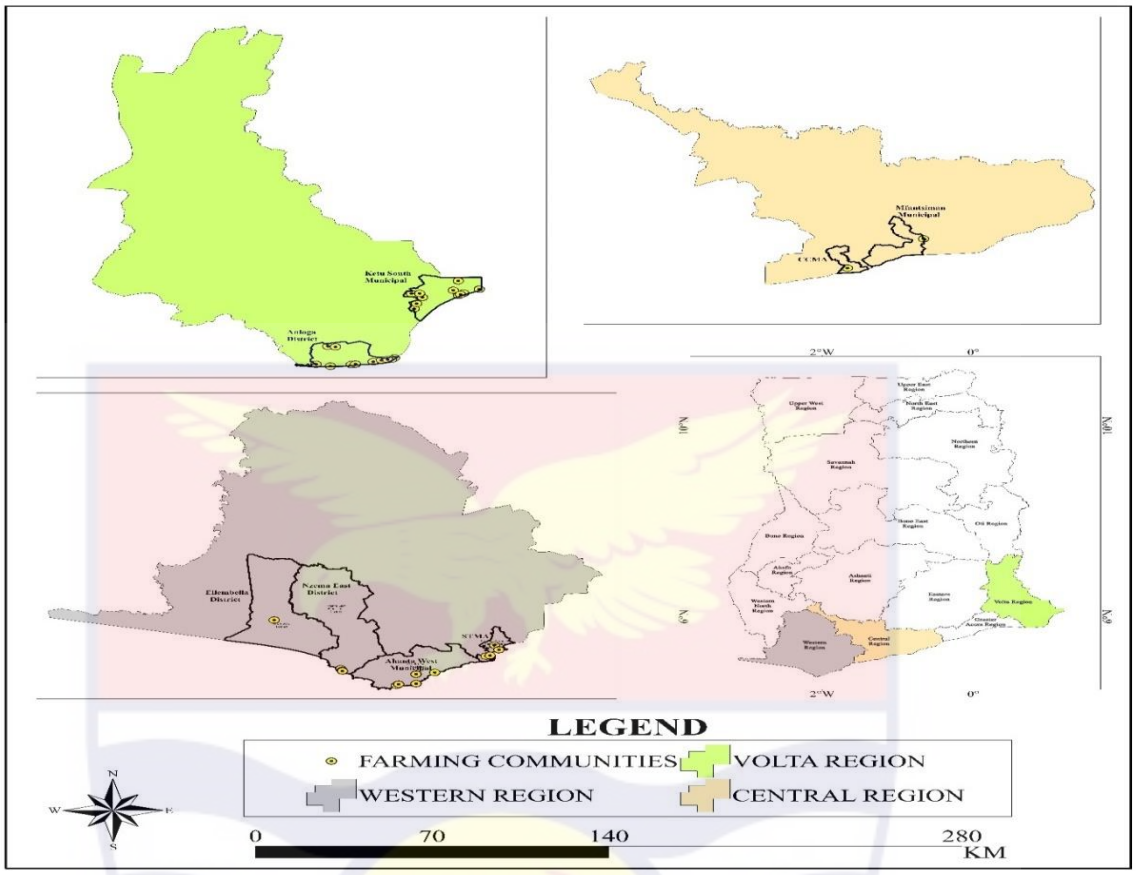


Figure 4.1: Ghana map showing geographical areas of farming districts/municipalities/metropolitan/communities of the Western, Central and Volta Regions

Materials and methods

Study design, population and sampling

Population, the test for validity and reliability and the recruitment and training of field assistants were described in Chapter 3. The sampling procedures have been described in Chapter 3. However, a total of 420 farmers sampled from 5 communities in the Western region, 160 farmers sampled from 2 communities in the Central region and 441 farmers sampled from 22 communities in the Volta region making a total of 1021 farmers across the three regions were necessary for representation according to Krejcie & Morgan (1970) sample size determination formula.

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Sources and data collection

Interviews with the respondents provided the primary data. Field notes were kept due to observations made in the field and casual conversations with certain important figures and opinion leaders in the study area. Age, sex, occupation, educational level, marital status, family income, size of the family, types of crops grown, sales of crops, use of organic manure, limitations of organic manure, perception of *Sargassum*-based compost, willingness to accept and purchase *Sargassum*-based compost, amount of money they were willing to spend on *Sargassum*-based compost, and qualities the respondents desired in *Sargassum*-based compost are among the socio-economic characteristics of the information gathered.

Ethical issues

Ethical issues are similar to the one described earlier in chapter 3 of this thesis.

Data processing and analysis

Before analysis, the quantitative data were cleaned, edited, coded and modified. All the quantitative data were captured first in Excel. It was later on copied onto SPSS. Finally, IBM-SPSS STATISTICS version 22 was used in data analysis. The procedures outlined in Chapter 3 were followed for descriptive statistics, analysis of variance (ANOVA) with the Post-hoc test, chi-square ($\chi 2$), and Friedman raking test. Kendall's coefficient of concordance was used to identify farmers' constraints to organic manure use. Farmers' use of organic fertilizer was ascertained by the application of binary logistic regression analysis. Using Stata Version 5 software, a double hurdle regression model was used to determine farmers' readiness to accept *Sargassum*-based compost and how much farmers are willing to pay for the compost.

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The Kendall coefficient of concordance (W) statistical model is calculated as follows:

W = (S / (m(m-1)/2)) ---------- [4.1]

Where:

- *W = Kendall coefficient of concordance (ranges from 0 to 1)*

- *S = sum of the squared differences between the rankings*

- *m = number of rankings or judges*

To calculate S, it needs to: Assign a rank (1, 2, …, n) to each evaluated item or object. Calculate the difference (di) between each pair of ranks for each item.

Square each difference (di^2).

Sum the squared differences (∑di^2) for all items.

Multiply the sum by the number of rankings (m).

Then, plug the values into the formula to get W.

The logistic regression model uses the following formula:

P = 1 / (1 + e^(-z)) ---------- *[4.2]*

Where:

- *p = probability of the event occurring (between 0 and 1)*

- *e = base of the natural logarithm (approximately 2.718)*

- *z = linear combination of the predictor variables*

The z-value is calculated as:

*Z = b0 + b1_x1 + b2_x2 + … + bn*xn* ---------- *[4.3]*

Where:

- *b0 = intercept or constant term*

- *bi = regression coefficient for the i-th predictor variable*

- *xi = value of the i-th predictor variable*

Results

Background characteristics of farmers

The result indicated that 33.8% of the farmers were 50-59 years old, while 27.9% had ages between 40-49 years. Moreover, 21.9% of those surveyed were in the

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60–69 age range. Table 4.1 showed that the farmers ranged in age from 20 to 80 years old. Female farmers comprised 25.4% of the total, while men made up of 74.6% of the farmer population (Table 4.1). Student farmers were 6.6% compared to 92.1% of farmers. Furthermore, 0.9% worked as farm assistants and 0.4% as farm supervisors.

Of the farmers, 29% had primary school education, while 23.6% had middle school education. In addition, 17.7% of respondents had tertiary education, 13.3% had an SSS education and 6.8% had no formal education. In terms of marital status, 7.0% of the farmers were single and 84.7% were married. While 1.5% of farmers were widows or widowers, 6.9% of them divorced (Table 4.1). Furthermore, while 37.6% had a family size of 4-6, 48% of the respondents had a family size of 7-9 (Table 4.1). The descriptive statistics revealed that the farmers had a minimum of 1 family size and 16 as a maximum family size (Table 4.1). Concerning the farmers' years in crop production, 44.7% had between 11-20 years in farming, 17.8% between 21-30 years in farming, 14.4% between 1-10 years and 0.9% between 51-60 years in farming (Table 4.1). The descriptive statistics revealed that farmers had a minimum experience of 1 year in crop farming and a maximum of 60 years of crop farming (Table 4.1). Most farmers (94.9%) sold their crops soon after harvest, while 5.1% stored their farm produce after harvesting (Table 4.1). While 67.1% of the farmers made a profit on the sale of produce, 3.7% of them made losses and 29.2% of the farmers made both profit and loss on the sales of the produce.

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Table 4.1: Background characteristics of farmers

Characteristics	Frequency	Percentages
Age		
20-29	74	7.2
30-39	53	5.2
40-49	303	29.7
50-59	345	33.8
60-69	224	21.9
70-79	20	2.0
80-89	2	0.2
Total	1021	100.0
Sex		
Male	762	74.6
Female	259	25.4
Total	1021	100.0
Occupation		
Fisherman/farmer	1	0.1
Farmer	940	92.1
Student Farmer	67	6.6
Farm Supervisor	4	0.4
Farm Assistant	9	0.9
Total	1021	100.0
Educational		
No Formal Education	69	6.8
Primary	296	29.0
JSS	98	9.6
Middle	241	23.6
SSS	136	13.3
Tertiary	181	17.7
Total	1021	100.0
Marital status		
Single	71	7.0
Married	865	84.7
Divorced	70	6.9
Widow/Widower	15	1.5
Total	1021	100.0
Characteristics	**Frequency**	**Percentages**
Family size		
1-3	30	3.1
4-6	370	37.6
7-9	472	48.0
10-12	99	10.1
13-15	11	1.1
>15	1	0.1
Total	983	100.0

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Table 4.1 continued

Years in crop farming		
1-10	146	14.4
11-20	454	44.7
21-30	181	17.8
31-40	114	11.2
41-50	112	11.0
51-60	9	0.9
Total	1016	100.0
Sale of crops after harvest		
Soon after harvest	969	94.9
Store	52	5.1
Total	1021	100.0
Do you make a profit or a loss?		
Profit	685	67.1
Loss	38	3.7
Both	298	29.2
Total	1021	100.0

Descriptive Statistics

Variable	Minimum	Maximum	Mean	Std. deviation
Age of farmers	20.00	80.00	51.0509	11.45457
Family size	1.00	16.00	7.2218	2.18951
Number of crops produced	2.00	15.00	8.2840	3.19184
Years in crop production	1.00	60.00	21.8957	13.05641

Different crops produced by farmers

Descriptive statistics revealed that 2 crops and 15 crops minimum number and maximum number of crops were produced by farmers respectively (Table 4.1). In the three regions, okra came first in terms of production with 11.8%, followed closely by tomatoes (8.6%), maize (8.1%), onion (7.1%), pepper (7.0%), cabbage (6.8%) and cucumber (6.4%). Coconut had the lowest percentage of crop production (3%) (Table 4.2).

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Table 4.2: Different crops produced by farmers

Crops	Frequency	Percentage
Okra	120	11.8
Tomatoes	88	8.6
Shallots	29	2.8
Spring onion	30	2.9
Onion	73	7.1
Pepper	71	7.0
Carrot	61	6.0
Lettuce	26	2.5
Cucumber	65	6.4
Beetroot	20	2.0
African spinach	38	3.7
Sweet potato	9	0.9
Garden eggs	59	5.8
Cabbage	69	6.8
Maize	83	8.1
Cassava	59	5.8
Yam	20	2.0
Coconut	3	0.3
Oil palm	33	3.2
Cocoa	32	3.1
Plantain	33	3.2
Total	1021	100.0

Regional cross-tabulation of farmers' age

Significant differences (χ^2 = 499.911[a], P < 0.001) existed among the age of respondents (Table 4.3). In the Volta region, the greater proportion of respondents (153) were in the age groups between 60-69 years, followed by 132 in the age group between 40-49 years and 116 in the age group between 50-59 years (Table 4.3). In the Central region, a greater proportion of the farmers (69) were in the age groups between 20-29 years. This was followed by 36 farmers aged 60-69 years, followed by 23 between 40-49 and 50-59 years (Table 4.3). Moreover, 206 farmers in the Western Region were in the 50–59 age range, with 140 farmers aged being aged between 40-49 years. However, in the three regions, a total of 345 farmers were in the age brackets of 50-59 years, while 305 of them were in the age group of 40-49 (Table 4.3).

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Table 4.3: Regional cross-tabulation of farmers' age

Region	20-29	30-39	40-49	50-59	60-69	70-79	80-89	Total
Volta	3	23	132	116	153	14	0	441
Central	69	3	23	23	36	4	2	160
Western	2	27	148	206	35	2	0	420
Total	74	53	303	345	224	20	2	1021

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	499.911[a]	12	0.000

Regional cross-tabulation of the gender of farmers

Significant differences (χ^2 = 13.750[a], P < 0.001) existed among the gender of respondents (Table 4.4). In the Volta region, 353 farmers were males, while 88 were females. In the Central region, there were 119 male farmers and 41 female farmers. In addition, in the Western region, the greater proportion of farmers was 290 males, compared to their female counterpart of 130 farmers. In the three regions, the total number of male farmers amounted to 762 while the total number of females was 259 (Table 4.4).

Table 4.4: Regional cross-tabulation of gender of farmers

Region	Male	Female	Total
Volta	353	88	441
Central	119	41	160
Western	290	130	420
Total	762	259	021

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	13.750[a]	2	0.001

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Regional cross-tabulation of occupation of farmers

Significant differences (χ^2=473.441[a], P <0.001) existed among respondents' occupations (Table 4.5). In the Volta region, most of the respondents (441) were farmers. However, in The Central region, while 79 respondents were farmers, 67 were student farmers, 4 were farm supervisors and 9 were farm assistants. Furthermore, in The Western region, 420 of the respondents were farmers (Table 4.5).

Table 4.5: Regional cross-tabulation of occupation of famers

Region	Fisherman & Farmer	Farmer	Student Farmer	Farm Supervisor	Farm Assistant	Total
Volta	0	441	0	0	0	441
Central	1	79	67	4	9	160
Western	0	420	0	0	0	420
Total	1	940	67	4	9	1021

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	473.441[a]	8	0.000

Regional cross-tabulation of the educational level of farmers

Significant differences (χ^2 =519.551[a], P < 0.001) existed among the educational levels of farmers (Table 4.6). In the Volta region, 242 farmers had primary education, and 131 had middle school education. It was found that 38 farmers in the Central region lacked any form of formal education, while the majority (70) had tertiary education. In the Western region, 108 farmers also obtained tertiary education, 102 had middle education, and 97 had SSS education (Table 4.6).

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Table 4.6: Regional cross-tabulation of educational levels of farmers

Region	No Formal Education	Primary	JSS	Middle	SSS	Tertiary	Total
Volta	15	242	26	131	24	3	441
Central	38	22	7	8	15	70	160
Western	16	32	65	102	97	108	420
Total	69	296	98	241	136	181	1021

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	519.551[a]	10	0.000

Regional cross-tabulation of the marital status of farmers

Significant differences (χ^2 =118.260[a], P < 0.001) existed among the marital status of respondents (Table 4.7). In the Volta region, 408 farmers were married, 19 were divorced, 9 were widows/widowers and 5 were single. In the Central region, the greater proportion of the farmers (107) married, while 40 were single. In the Western region, 350 farmers married, followed by 41 who divorced their spouses. In the three regions, 865 of the farmers were married (Table 4.7).

Table 4.7: Regional cross-tabulation of the marital status of farmers

Region	Single	Married	Divorced	Widow/Widower	Total
Volta	5	408	19	9	441
Central	40	107	10	3	160
Western	26	350	41	3	420
Total	71	865	70	15	1021

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	118.260[a]	6	0.000

Regional cross-tabulation of family sizes of farmers

Significant differences (χ^2 =134.577[a], < 0.001) existed among the family sizes of farmers (Table 4.8). In the Volta region, while 199 farmers had family

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sizes of 4-6 people, 170 had a family size of 7-9 people. In the Central region, 61 farmers had a family size between 4-6 people while 24 had family sizes between 7-9 and 10-12 people, apiece. In the Western region however, 278 farmers had a family size of 7-9 people followed by 110 of them having a family size of 4-6. In the three regions, the highest number of farmers (472) had family size between 7-9 people, followed by a total of 370 of them having a family size of 4-6 people (Table 4.8).

Table 4.8: Regional cross-tabulation of family sizes of farmers

Region	1-3	4-6	7-9	10-12	13-15	16-30	Total
Volta	12	199	170	51	6	0	438
Central	11	61	24	24	4	1	125
Western	7	110	278	24	1	0	420
Total	30	370	472	99	11	1	983

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	134.577[a]	10	0.000

Regional cross-tabulation in years (experience) of farming by farmers

Significant differences (χ^2 = 729.927[a], P < 0.001) were noticed in the years of farming by farmers (Table 4.9). In the Volta region, 146 farmers had a farming experience of 21-30 years, while 102 had a farming experience of 31-40 years. Surprisingly, 90 farmers had a farming experience of 41-50 years and only 4 had a farming experience of 51-60 years. Nonetheless, the majority of farmers in the Central region (82) had between one and ten years of experience, while 25 had between eleven and twenty years. In the same way, as in the Volta region, 22 and 5 farmers had farming experience of 41-50 years and 51-60 years respectively. In addition, 348 farmers in the Western region had been farming for 11–20 years, whereas 47 had been farming for 1–10 years (Table 4.9).

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Table 4.9: Regional cross-tabulation in years (experience) of farming by farmers

Region	1-10	11-20	21-30	31-40	41-50	51-60	Total
Volta	17	81	146	102	90	4	440
Central	82	25	16	10	22	5	160
Western	47	348	19	2	0	0	416
Total	146	454	181	114	112	9	1016

Chi-square test			
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	729.927[a]	10	0.000

Regional cross-tabulation of time of sales of crops by farmers

Significant (χ^2 =78.403[a], P < 0.001) differences existed in the time of sales of crops by farmers (Table 4.10). In the Volta and Central regions, 441 and 160 farmers respectively sold their crops soon after harvest without storage. However, 368 farmers sold their crops soon after harvest in the Western region, while 52 stored the farm produce to meet market demand (Table 4.10).

Table 4.10: Regional cross-tabulation of time of sales of crops by farmers

Region	Soon after harvest	Store	Total
Volta	441	0	441
Central	160	0	160
Western	368	52	420
Total	969	52	1021

Chi-square test			
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	78.403[a]	2	0.000

Regional cross-tabulation of profit and loss of crop sales by farmers

Significant differences ($\chi 2 = 260.531$, P<0.001) were observed in farmers' profit and loss of crop sales (Table 4.11). In the Volta region, 231 farmers made both profit and loss, 206 farmers made a profit and only four farmers made a loss after sales of farm produce. In the Central region, 103 of the farmers made a profit, while four made losses, and 53 made both profit and loss on sales of their farm produce. Furthermore, in

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the Western region, most farmers (376) made a profit while 30 made losses, with only 14 making both profit and loss (Table 4.11).

Table 4.11: Regional cross-tabulation of profit and loss of crop sales by farmers

Region	Profit	Loss	Both	Total
Volta	206	4	231	441
Central	103	4	53	160
Western	376	30	14	420
Total	685	38	298	1021
		Chi-square test		
	Value	Df		Asymptotic Significance (2-sided
Pearson Chi-Square	260.531[a]	4		0.000

Uses of organic manure by farmers

A greater proportion of farmers (91.6%) responded in the affirmative that they had used organic manure before, while a minority of them (8.4%) responded no to organic manure usage (Table 4.12). On the type of organic manure farmers had used before, most of them (28.1%) used cattle manure, 18.4% used farm yard manure, 16.2% used poultry manure, 16.0% used organic liquid fertilizer and 15.3% used compost. While 5.2% depended on human excreta, 0.8% used guano (bat droppings) (Table 4.12).

On the factors that influence their choice of organic manure, a greater proportion of the farmers (39.2%) responded that it was cheap followed by 38.9% of them responding that it released nutrients slowly, with 21.9% of the farmers also responding that it restored the soil.

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Table 4.12: Uses of organic manure by farmers

Questions	Responses	Frequency	Percentage
Have you used any organic fertilizer before?	Yes	934	91.6
	No	87	8.4
	Total	1021	100.0
Mention the different types of organic fertilizer you have used before			
	Poultry manure	165	16.2
	Farmyard manure	188	18.4
	Human excreta	54	5.2
	Cattle manure	287	28.1
	Compost	156	15.3
	Organic liquid fertilizer	163	16.0
	Bat guano droppings	8	0.8
	Total	1021	100.0
What factor(s) influence your choice and use of organic manure?			
	Cheap	400	39.2
	Slow release of nutrient	397	38.9
	Restoration of soil	224	21.9
	Total	1021	100.0

Regional cross-tabulation of organic manure uses by crop farmers

Significant difference (χ^2 =129.118[a], P < 0.001) were seen in the farmers' organic manure use (Table 4.13). A greater proportion of the farmers (414) responded yes in the Volta and Western regions while 110 responded yes in the Central region. Nonetheless, a higher percentage of farmers in the Central region (50) stated that they do not utilize organic manure. In the Volta and Western regions (27 and 9 farmers) responded that they do not use organic manure (Table 4.13).

Table 4.13: Regional cross-tabulation of organic manure uses by crop farmers

Region	Yes	No	Total
Volta	414	27	441
Central	110	50	160
Western	414	9	420
Total	935	85	1021
	Chi-square test		
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	129.118[a]	2	0.000

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Regional cross-tabulation of factors preventing farmers use of organic manure

Significant differences (χ^2 =1120.475[a], P < 0.001) existed in the factors preventing farmers from using organic manure (Table 4.14). In the Volta region, most farmers (288) responded that, they could not use organic manure because there was usually no market for organically produced crops. Again 36 of the farmers in the Volta region said that organic products were of low quality. At the same time, 89 said they did not use it due to their non-availability. However, in the Western region, all the farmers (411) responded that the only reason they could not use organic manure was its non-availability. None of the farmers in the Western region spoke about the quality of the organic produce. Furthermore, in the Central region, 60 farmers responded that offensive odour and bulkiness discouraged them from using organic manure. Again 25 of the farmers in the Central region said that organic manure was of low quality (Table 4.14).

Table 4.14: Regional cross-tabulation of factors preventing farmers use of organic manure

Region	No mkt for produce	Low quality of product	Non-availability	Bulky &Offensive odour	Total
Volta	288	36	89	1	414
Central	2	25	24	60	111
Western	0	0	411	0	411
Total	290	61	524	61	936

Chi-square test			
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	1120.475[a]	6	0.000

Organic manure determinants by farmers using logistic regression analysis

Ten (10) of these predictor variables were used to determine organic fertilizer use (Table 4.15). The model explained 18.9% (Cox and Snell R square) and 43.0% (Nagelkerke R square) of the reliability of variance in crop farmers' use of organic manure. This was found by regression analysis conducted for the independent and

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dependent variables. The goodness of fit test, also known as the Omnibus Test of Model Coefficients (Likelihood Ratio test) measured how well the model performed. The extremely significant ($\chi 2$=203.461, P < 0.001) differences suggested that, at least one parameter was not equal to zero and the model is well fitted. The Wald chi-squared statistics (i.e., 0.352 and 0.931, respectively) for family size and access to extension services are not statistically significant (Table 4.15). The remaining eight (8) variable predictors however, were statistically significant at the alpha level of 5% and 1%. These included age, gender, education, marital status, number of crops grown, number of years in farming, sale or storage of crops and access to credit (P = 0.044, P =0.000, P =0.002, P = 0.032, P = 0.000, P = 0.000, P = 0.000, and P =0.000, respectively) (Table 4.15).

Table 4.15: Organic manure determinants by farmers using logistic regression analysis

						95% C.I.for EXP(B)		
Variables	B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Age	.041	.020	4.066	1	.044	1.042	1.001	1.084
Sex	1.299	.307	17.931	1	.000	3.665	2.009	6.686
Education	-.358	.117	9.366	1	.002	.699	.556	.879
Marital status	-.687	.321	4.582	1	.032	.503	.268	.944
Family Size	.063	.067	.866	1	.352	1.065	.933	1.215
Number of crops	-.610	.103	35.305	1	.000	.543	.444	.664
Farming years	.156	.050	9.770	1	.002	1.168	1.060	1.288
Sale or storage of crops after harvest	-1.789	.482	13.776	1	.000	.167	.065	.430
Access to Credit	1.628	.311	27.381	1	.000	5.095	2.769	9.375
Access to Extension services	-.029	.329	.008	1	.931	.972	.510	1.850
Constant	.175	1.125	.024	1	.877	1.191		

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	359.106[a]	.189	.430

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Table 4.15 cont'd

Omnibus Test of Model Coefficients (Likelihood Ratio test)

		Chi-square	df	Sig.
Step 1	Step	203.461	10	0.000
	Block	203.461	10	0.000
	Model	203.461	10	0.000

Impact of organic fertilizer constraints usage by farmers

Significant differences F (2, 944) =16.088 and P= 0.000 existed among the farmers' responses in the three regions (Table 4.16). To explore further in which of the regions the significant differences existed, a post-hoc test using Tukey Honestly Significant Difference (THSD) was done. The impact of organic fertilizer limitations on farmers varied significantly between the Volta region (-.14066* = P<001) and the Central region (-.21774* = P<001) with significance at the P <0.05 level. Significant difference existed between Western and Volta Regions (.14066* =P<001) and also between Western region and Central regions (.21774* =P<001).

Table 4.16: Impact of organic manure constraints usage by farmers using ANOVA and Post-hoc Tukey test

Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	6.288	2	3.144	16.088	.000
Within Groups	184.480	944	.195		
Total	190.768	946			

	Post Hoc (Tukey HSD)	**Multiple**	**Comparison**		**95% confidence interval**	
(I) Region Name	**(J) Region Name**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**Lower Bound**	**Upper Bound**
Volta	Central	.07708	.04707	0.230	-.0334	.1876
	Western	-.14066*	.03060	0.000	-.2125	-.0688
Central	Volta	-.07708	.04707	0.230	-.1876	.0334
	Western	-.21774*	.04701	0.000	-.3281	-.1074
Western	Volta	.14066*	.03060	0.000	.0688	.2125
	Central	.21774*	.04701	0.000	.1074	.3281

*. The mean difference is significant at the 0.05 probability level.

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Kendall's coefficient of concordance ranking of organic manure constraints

To determine the total of ranks for each indication that each farmer scored and then investigate the variability of this sum, Kendall's coefficient of concordance was used. From the results the bulkiness of organic manure obtained the highest mean rank of 3.62 (Table 4.17). This implies that it is the most organic manure constraint based on crop farmers' assessment. The second and third most common organic manure constraints ranked by crop farmers were offensive odour (W=3.53) and difficult to transport from one place to another (3.32) respectively. In addition, the fourth and fifth most common organic manure constraints were a slow release of nutrients and doubtful efficacy (W=3.17 and 1.36 respectively) (Table 4.17). Given that the crop producers' Kendall's W value was 0.586, the results indicated a high degree of agreement among them. The farmers intuitively agreed on a high degree of importance when it came to the limitations of using organic manure. Furthermore, this level of agreement on the organic constraints is highly significant at 1% alpha level (χ^2 = 2218.392; df = 4, P<0.001).

Table 4.17: Kendall's coefficient of concordance ranking of organic manure constraints

Constraints of organic manure	Mean rank	Standard deviation	Rank position
(a) Bulkiness	3.62	0.54459	1st
(b) Offensive odour	3.53	0.56211	2nd
(c) Difficult to transport	3.32	1.07824	3rd
(d). Slow release of nutrients	3.17	0.73441	4th

Kendall's W Statistics	
N	946
Kendall's Coefficient of Concordance (W[a])	0.586
Chi-Square	2218.392
Df	4
Asymp. Significance	0.000

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Awareness of benefits and use of *Sargassum* compost using ANOVA and Post-hoc Tukey test

Significant differences (F (2, 1018) =597.301 and P = 0.000 existed between the responses from the farmers in the three regions. The benefits of compost made from *Sargassum* spp. varied significantly at the P<0.05 level across the Volta region (3.22857* = P<001), Central and Western regions (3.22857* = P<001). There was a substantial difference between the Western and Volta regions (-3.22857*=P<001) and also between the Western and Central region 3.22857*=P<001) (Table 4.18).

Table 4.18: Awareness of benefits and use of Sargassum compost using ANOVA and Post-hoc Tukey test

Variables	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2577.026	2	1288.513	597.301	0.000
Within Groups	2196.057	1018	2.157		
Total	4773.083	1020			

	Post Hoc (Tukey HSD)	Multiple	Comparison		95% Confidence Interval	
(I) Region Name	**(J) Region Name**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**Lower Bound**	**Upper Bound**
Volta	Central	0.00000	.13555	1.000	-.3182	0.3182
	Western	3.22857*	.10014	0.000	2.9935	3.4636
Central	Volta	0.00000	.13555	1.000	-.3182	0.3182
	Western	3.22857*	.13645	0.000	2.9083	3.5488
Western	Volta	3.22857*	.10014	0.000	-3.4636	2.9935
	Central	3.22857*	.13645	0.000	-3.5488	2.9083

*. means significant difference at the 0.05 probability level

Friedman ranking test of the benefits of *Sargassum*-compost

The chi-square (χ^2 = 39.495, P < 0.001) indicated significant differences among the farmers' responses on the benefits of *Sargassum* spp. compost (Table 4.19). During the regional cross-tabulation, the mean rank of 2.97 was the lowest, indicating that the farmers agreed that compost's ability to suppress pest populations in crop production was most beneficial to them. Hence it was ranked 1st. The highest mean rank was 3.03, indicating that all the farmers agreed that the compost's ability to contain nitrogen,

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phosphorus and potassium can retain significant nutrients for crop growth and development is less beneficial to them hence it is ranked 5th (Table 4.19).

Table 4.19:Friedman rank test of the benefits of Sargassum-compost

Farmers Knowledge of the importance of Sargassum-based compost	Mean Rank	Standard Deviation	Rank Position
Are you aware of the following benefits of *Sargassum*-based organic manure ?:			
a). Suppression of plant pest populations	2.97	.44831	1st
b). Mineralization, cation exchange capacity& increase in microbial activity	2.98	.44585	2nd
c). Organic matter accumulation and carbon exchange capacity	3.01	.44073	3rd
d). Increased soil water holding capacity & improved soil aeration	3.02	.43806	4th
e). Contain nitrogen, phosphorus and potassium, and can retain more nutrients for crop growth and development	3.03	.43588	5th
Friedman test statistics			
N	1021		
Chi-Square	39.495		
df	4		
Asymp. Sig.	0.000		

Farmers' willingness to accept and buy *Sargassum* compost

Significant differences (χ^2 =34.519[a], P < 0.001) existed in the farmers' willingness to accept and buy *Sargassum* spp. compost (Table 4.20). In the three regions, the significant proportion of farmers (Volta=427, Central=142 and Western=359) responded that they were willing to accept and buy *Sargassum* spp. compost as against the lesser proportion of farmers (Volta=14, Central=18 and Western=61) who responded that they were not willing to accept and buy *Sargassum* spp. compost (Table 4.20).

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Table 4.20: Farmers' willingness to accept and buy *Sargassum*-compost

Region	Yes	No	Total
Volta	427	14	441
Central	142	18	160
Western	359	61	420
Total	928	93	1021

Chi-square test

	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	34.519[a]	2	0.000

Farmers' willingness to accept and buy *Sargassum*-compost using mixed-process regression (Double hurdle)

The model is fit to purpose, and at least some of the variables are significant as revealed by the Wald χ^2 **(**725430.51), P> χ^2 =0.0000. In the first hurdle, which is the willingness to accept and buy *Sargassum* spp compost, only two (2) variables (family size and number of crops produced by farmers) were significant at 1% with coefficients of 0.050 and 0.148, respectively. At an alpha level of 5%, the remaining variables (age, gender, marital status, educational attainment, number of years spent in crop production, credit, and availability of extension services) were not significant, with coefficient values of 0.013, -0.078, 0.039, 0.022, 0.015, -0.029, and 0.208, respectively. Family size, years in crop production, number of crops, and access to extension services, on the other hand, were all significant at an alpha level of 1% in the second hurdle (willingness to pay for compost), with coefficient values of 2.907, -0.588, 7.670, and 3.846, respectively (Table 4.21).

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Table 4.21: Farmers' willingness to accept and buy Sargassum-compost using mixed-process regression (Double hurdle)

Variable	Coef.	Std. Error.	z	P>z	[95%Conf.	Interval]
Willingness to accept compost						
Age	0.013	0.060	0.220	0.827	-0.104	0.130
Sex (Gender)	-0.078	1.373	-0.060	0.954	-2.769	2.612
Marital status	0.039	1.653	0.020	0.981	-3.202	3.279
Education	0.022	0.805	0.030	0.978	-1.556	1.600
Family size	0.050	0.013	3.910	.000**	0.025	0.075
Numb of crops	0.148	0.023	6.300	.000**	0.102	0.194
Years in crop production	-0.015	0.026	-0.580	0.564	-0.065	0.036
Access to credit	0.029	0.884	0.030	0.974	-1.703	1.760
Access to extension service	0.208	1.696	0.120	0.902	-3.116	3.531
_Constant	-1.009	0.217	-4.640	.000**	-1.434	-0.583
Willingness to pay for compost						
Age	0.252	0.200	1.260	0.206	-0.139	0.644
Education	1.139	.056	1.080	0.281	-0.930	3.209
Family size	2.907	0.635	4.580	.000**	1.663	4.152
Years in crop production	-0.588	.177	-3.320	.001**	-0.935	-0.240
Access to credit	2.782	.994	0.930	0.353	-3.086	8.650
Number of crops	7.670	.654	1.720	.000**	6.388	8.953
Access to extension service	3.846	.057	67.380	0.000**	3.734	3.958
Sex (Gender)	6.809	10.931	0.620	0.533	-14.616	28.234
_Constant	-27.155	9.020	-3.010	.003**	-44.833	-9.476
Model Summary						
No of observation	1,021					
Wald chi2(15)	725430.51					
Log pseudolikelihood	5375.8842					
Prob > chi2	0.000					

** =Significant at 1%

Factors farmers prefer in S*argassum* compost

Significant differences (χ^2 =309.525[a], P < 0.001) existed in the factors farmers are looking for in the *Sargassum* spp. compost (Table 4.22). In the Volta region, all the farmers responded that they wanted the compost produced to be rich in nutrients and all

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the farmers in the Central region (159) also responded that they were willing to accept the compost if it contained sufficient nutrients. However, in the Western region, while most farmers (205) responded that the compost should be rich in nutrients, 156 of the farmers wanted the compost to yield more crops (Table 4:22).

Table 4.22: Factors farmers prefer in *Sargassum*-compost

Region	Rich in nutrient	Yield more crop	Total
Volta	441	0	441
Central	159	0	159
Western	205	156	361
Total	805	156	961

Chi-square test			
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	309.525[a]	2	0.000

Prices farmers are willing to pay for 50kg *Sargassum* compost

Respondents were willing to pay as low as GH₵ 8.0 and as high as GH₵ 420.0 for the *Sargassum* compost (Table 4.23). Thirty percent (30%) of the farmers were able to pay between GH₵ 10.0-GH₵ 20.0. This was followed closely by 12.7% willing to pay an amount above GH₵ 100.0, 11.8% willing to pay an amount of GH₵ 31.0-GH₵ 40.0 and 10.8% of farmers willing to pay GH₵ 41.0-GH₵ 50.0. The lowest percentage of farmers (1%) were willing to pay less than GH₵ 10.0 (Table 4.23).

Table 4.23: Prices farmers are willing to pay for 50 kg Sargassum-compost

Amount /GH₵	**Frequency**	**Percentage**
<10	10	1.0
10-20	288	30.0
21-30	47	4.9
31-40	113	11.8
41-50	98	10.2
51-60	88	9.2
61-70	48	5.0
71-80	51	5.3
81-90	32	3.3
91-100	62	6.5
>100	122	12.7

Descriptive statistics				
N	Minimum	Maximum	Mean	Std. Deviation
965	GH₵ 8.0	GH₵420.0	63.0819	55.2774

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Reasons farmers gave for the choice of price for 50 kg *Sargassum* compost

Significant differences (χ^2 =160.610[a], P < 0.001) existed in the reasons given for the choice of prices offered by farmers for the 50 kg *Sargassum* compost (Table 4.24). In the Volta region, the majority of the farmers (182) responded that the choices of prices offered were what they could afford to pay. One hundred and thirty-four (134) of the farmers said they were not willing to pay much until they tested the produce on crops to see its efficacy and 125 farmers believed that they were paying such an amount because they believed the compost would be good. In the Central region, 64 farmers responded that until they saw the compost and knew its efficacy on crops, they would not pay much for it, while 49 said they believed the product would be good. Furthermore, in Western region while 211 farmers responded that the amount they were paying for the compost was what they could afford, 152 believed the product would be good, hence, they could pay more (Table 4:24).

Table 4.24: Reasons farmers gave for the choice of price for 50kg Sargassum compost

Region	Until I test it on crops first, I will not pay much	This is what I can afford	I believe the product will be a good one	Total
Volta	134	182	125	441
Central	64	47	49	160
Western	0	211	152	363
Total	198	440	326	964

	Chi-square test		
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	160.610[a]	6	0.000

The texture of the *Sargassum*-compost preferred by farmers

Significant differences (χ^2 =14.219[a], P=0.001) existed in the texture of *Sargassum* compost farmers preferred (Table 4.25). In the Volta region, most farmers (417) preferred the compost to be in granular form, while minority (12) wanted the compost to be in powdered form. However, in the Central and Western regions, all the

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farmers (135 and 381, respectively) responded that they preferred the *Sargassum* compost in granular form (Table 4.25).

Table 4.25: Texture of the *Sargassum*-compost preferred by farmers

Region	Granular	Powdered form	Total
Volta	417	12	441
Central	135	0	135
Western	381	0	381
Total	933	12	957

Chi-square test			
	Value	Df	Asymptotic Significance (2-sided
Pearson Chi-Square	14.219[a]	2	0.001

Discussion

Background characteristics of farmers

Results indicated that crop farming in this study was a male dominated business, with the majority of the farmers obtaining ages between 50-59 years. In addition, most farmers had primary education. Furthermore, while most farmers married, their family size ranged between 7-9 members.

The rationale was that men had an advantage over women in farming because of the cultural settings of the Volta, Central and Western regions, which made it simple for men to acquire land and production input. This is in agreement with researchers who reported that more men than women were engaged in agricultural production, whereas females were mostly involved in harvesting, processing and marketing (Igwe & Onyenweaku, 2013; Larkai, 2019; Koufie, 2020; Oladeji, Oyedoku, & Bankole, 2001).

Research had demonstrated that age and affiliation with a group, association or organization are significant social capital, ensuring or providing knowledge, skills and information (Kalineza *et al.,* 1999; Mamudu *et al.,* 2012). The majority of the farmers in this survey were older than 40 suggesting that young people were not interested in farming since they did not think it was a rewarding profession. As a result, they let the

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adult population handled it. The study's conclusions align with those of Koufie (2020), but disagree with Wongnaa (2016) who asserted that elderly workers made up the most productive labour force in the maize industry (Table 4.1).

Education plays a critical role in enhancing an individual's understanding of the world and enabling them to make informed decisions. The study's findings support Koufie's (2020) report that farmers having a basic education were more likely to accept and use new technology on their farms as well as the reports of Igwe & Onyenweaku (2013) that farmers were relatively literate despite findings from Owusu-Amankwa (2018) and Larkai (2019) that the majority of farmers were illiterate.

All things being equal, married people give birth and if they are blessed with many children, these children would constitute a strong labour force. In addition, women concentrate on processing and marketing of farm produce.

The current study's family size (7-9 members) was above that of the Ghana Statistical Service (GSS, 2021) National Housing and Population Census in 2021, which reported a household size of 3.5-4. This study, however, supports the findings of Babasola *et al.* (2017) who revealed that the average household size of Nigerian vegetable growers was 7.2, much larger than the state and national average household sizes of 4.9 and 5.9, respectively (FAO, 2006). This study was consistent with research from Effiong (2005) and Igwe & Onyenweaku (2013) which reported that having a big family boosts family labour and lowers labour costs in agricultural productivity.

Years in farming (experience)

The farming experience of the majority of farmers corresponds with those aged 11-20 years in farming. This indicated that there was a push for more individuals to become farmers. The results corroborated the finding by Abdullai, Nkegbe & Donkor

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et al. (2017) that agricultural growers lacked experience. Farmers typically had one year to sixty years of farming expertise.

Sales or storage of crops after harvest

All farmers from the Volta and Central regions could not store their farm produce perhaps because most of these crops were highly perishable, containing high percentages of water. The Western region's farmers, however, stored, their crops after harvest. For example, the sun hardly shines in the Nzema East district hence, their crop never dried up, so, they processed the half-dried corn into corn dough (Ridwan Haruna, District Director of Agriculture, Nzema East, Personal Communication, 2023).

Profit or Loss during sales of crop

In the three regions (Volta, Central and Western), most of the farmers made profit rather than a loss. The profit probably resulted from prudent management of fertilizers and agro-inputs (Lawrence Dormenyo, District co-operative vegetable producer's secretary, Anloga District, Personal Communication, 2023).

Different crops produced by farmers in the three regions

The study revealed that okra was the most-produced vegetable in the three regions. This study agrees with research by Chagomoka *et al*. (2015) who reported that over 45% of women of reproductive age consumed okra. This study, however, conflicts with those of Opong-Sekyere *et al.* (2012), who found that okra plays a significant part in food preparation, and in Ghana, it is the fourth most extensively grown vegetable behind pepper, tomato and garden eggs. Kessler *et al*. (2004) reported that although okra and other crops like jute mallow are thought to be less profitable, they were grown mostly for subsistence consumption. Additionally, growing vegetables had a significant potential to produce additional revenue and essential micronutrients that may be utilized to meet household food needs (Kamga *et al.,* 2013; Weinberger & Lumpkin, 2007).

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Uses of organic manure by farmers

Organic manure was used perhaps, because they were cheap, released nutrients slowly and restores the soil. This study supports the findings of researchers who used cattle manure, poultry droppings and other organic fertilizers to produce vegetables (Babasola *et al*., 2017; Alimi *et al.*, 2006; Ajewole, 2010).

Predictors of organic manure use by farmers using logistic regression analysis

The study's results indicated that, the more the farmers grew in age, the more they used organic manure as indicated by their positive Beta value (0.41). Both males and females were willing to use organic manure because they trusted it, as indicated by their positive beta value (1.299). However, the more educated the farmers became, the more they were willing to use organic manure and vice versa, as indicated by the negative beta value (-.358). In the same way farmers showed appreciation for using organic manure if only they were married and used less organic manure when they were not, as indicated by their negative beta value of -.687. The farmers also indicated that the more crops they grew, the more organic manure they could use and vice versa, based on their negative beta value (-0.610). Moreover, the farmers believed that the more organic manure they used, the more crops they could harvest, sell or store and vice versa as indicated by their beta value of -0.1.787. However, the farmers indicated that the more access to credit they had the more organic manure they could buy and use as indicated by their positive beta value (0.1.628). This study supports that of Babasola *et al*. (2017), who posited that more vegetable farmers used organic manure in Kwara state, Nigeria. The null hypothesis, which says farmers are unaware of organic fertilizer and do not use it is rejected.

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Factors that prevent or inhibits farmers from using organic manure.

In the Volta region, even though farmers used organic manure alone to produce healthy and quality crop, no market existed for such crop. In the Central region, farmers did not prefer using organic manure because it was bulky and posed transportation difficulty. This study concurs with researchers' findings which reported that transportation, unpleasant odour and lack of assurance about the manure's efficacy prevented farmers from using organic manure (Odhiambo & Magandini, 2008; Alimi *et al*., 2006).

Even though the fertilizer was brought to the Western region, they found it difficult to access and use it although few people got access to it. The null hypothesis is rejected in favour of the alternative hypothesis that there are factors that prevent/inhibit farmers from using organic manure.

Impact of constraints of organic manure use by farmers

The three regions felt differently about the limitations of organic manure, which included bulkiness, an unpleasant smell, transportation difficulties, a delayed rate of nutrient release and questionable efficacy. This may be due to the soil diversification, climatic condition and financial status of farmers across the regions. This rejects the null hypothesis that farmers are unaware of organic manure constraints. This study concurs with that of Babasola *et al.* (2017) who noted that organic manure-related obstacles, including transportation, odour, labour expenses, application complexity, influenced vegetable producers in Kwara state, Nigeria. The study also agrees with Alimi *et al.* (2006) who stated that barriers to applying organic manure in crop production include bulkiness, unpleasant odour, slow action, transportation challenges and dubious efficacy.

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Degree of agreement among farmers in ranking constraints of organic manure

The study's conclusions suggested that crop producers in the research regions had a consensus regarding the order of the metrics for organic manure rankings. The bulkiness of organic manure, according to the farmers, was the biggest constraints, followed by unpleasant odour, transportation, slow-releasing nutrients and questionable efficacy in that order. As a result, the alternative hypothesis is accepted that there is agreement among farmers regarding the order of their views toward organic fertilizer constraints. This study contradicts the conclusions of Babasola *et al.* (2017), Odhiambo & Magandini (2008) and Alimi *et al.* (2006) who posited that the barriers to the use of organic manure were transportation, ambiguity about their efficiency and their foul odour.

Awareness of the benefits of *Sargassum* compost

The post-hoc test indicated that significant differences existed among the farmers in all the three regions. This study concurs with Barbanti *et al.* (2010), Agegnehu *et al.* (2015) and Aggelides (2000) who found that *Sargassum* compost would release nutrients slowly and promote development of roots, improve soil tilth and enhances the water-holding capacity of substrates and increase microbial diversity (Kowaljow & Mazzarino, 2007; Xu *et al.*, 2012). The null hypothesis is rejected which stated that farmers are not aware of the importance of *Sargassum* compost in favour of the alternative.

The benefits of *Sargassum* spp. compost using the Friedman ranking test

The farmers believed that the suppression of plant pest populations by *Sargassum* compost was most beneficial and that *Sargassum* compost containing nitrogen, phosphorus and potassium and how they could retain more nutrients for crop growth and development were least beneficial to the farmers. These farmers, perhaps

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were aware that every compost contains N, P and K. Hence the most ranked benefit of *Sargassum* spp. compost will play a double role in boosting crop growth and in the same way suppress plant pest populations.

Farmers' willingness to accept and buy *Sargassum* compost

In the case of *Sargassum* spp. which was a newly introduced technology, especially in the lower basin of the Atlantic Ocean, most farmers were willing to accept *Sargassum* compost and use it. This study supports the findings of Waliczek *et al.* (2020) that participants were willing to buy *Sargassum* compost and Abdool-Ghany *et al.* (2023) who found that farmers were willing to pay \$35/m^3 for seaweed-incorporated compost. Adoption of agricultural technology is an end user's decision as reported by Bonabana-Wabbi (2002). The null hypothesis is rejected, which states that farmers are not willing to accept and buy *Sargassum* compost in favour of the alternative hypothesis.

Willingness to accept and pay for *Sargassum* compost using mixed-process regression

In the first hurdle, the family size was significant at 0.01 alpha level and positively related to the probability that farmers were willing to take *Sargassum* spp. compost. The study suggested that an increase in family size would enhance a farmers' ability of accepting *Sargassum*-compost by 0.050 units. Family size was utilized as a proxy for labour availability. This indicated that farmers with huge family sizes were more likely to go into farming using more of the compost after accepting it than those with a smaller family. This finding concurs with findings of researchers who reported that families with large people were most likely to accept more compost for different crop production (Babulo *et al.* 2014; Baba & Abdulai, 2021).

At an alpha level of one percent, the number of crops grown by farmers was significant and the coefficient value of 0.148 indicated a positive correlation between

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the adoption of *Sargassum* spp and the number of crops grown by farmers. At the 5% alpha level, credit and extension service accessibility was not significant. According to the findings, a farmer's likelihood of accepting compost made from *Sargassum* spp. would not rise with increased loan availability or access to extension services. The results contradict those of Bittinger (2010) who reported that farmers who accepted compost and received credit in the form of cash were more likely to grow crops than those who did not. Furthermore, the results corroborated the assertions made by Rehima *et al.* (2013) that extension services favourably and considerably influenced the acceptability of *Sargassum* compost for increased crop production.

When it came to the second hurdle (willingness to pay for compost), however, the coefficient values for 2.907, -0.588, 7.670 and 3.846 indicated that family size, years of crop production, number of crops and access to extension services, respectively were all significant at an alpha level of 1% (Table 4.21). Given that the farmers' coefficient values (2.907, 7.670 and 3.846, respectively) were positive, the results indicated that increasing family size, diversifying crop production, and extension services will raise the likelihood that the farmers will purchase compost and use it in crop production. Nevertheless, the years of agricultural experience (years-coefficient) of farmers was negative, indicating that farmers increase in the years of farming would reduce the willingness to pay for the *Sargassum* spp. compost by -0.588. The study agrees with Ibrahim *et al.* (2009) who discovered that extension contacts increased payment for compost to produce more crops. Rahman (2008) also reported that experienced farmers used crop production systems to benefit from high returns on investment for a particular crop, while applying and purchasing compost.

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Factors farmers are looking for in *Sargassum* compost

Farmers in Volta and Central regions believed the only factor they sought for in the *Sargassum* compost before accepting it for use was its nutrient richness. When this happened, they can stop using inorganic fertilizer, which is expensive nowadays. However, in the Western region, the farmers were divided in predicting the factors that *Sargassum* compost should have. Researchers in the literature have reported on the factors mentioned by these farmers in this study (Liu *et al.*, 2007; Toufack *et al.*, 2009; Heeb *et al*., 2006).

Prices farmers are willing to pay for *Sargassum* compost

In the Volta region for example, most farmers were willing to offer prices for the compost ranging from GH₵ 8.00-GH₵ 20.00 because at that time of the survey poultry dropping was being sold at GH₵ 20.00. In contrast, cattle manure was being sold at GH₵ 8.00 hence, these farmers were not prepared to offer any price above the prices of poultry droppings and cattle manure. In The Central Region, farmers in the UCC's School of Agriculture Teaching and Research farm used poultry manure and compost hence they were unwilling to pay higher prices for the *Sargassum* compost. However, in the Western region, most farmers were willing to pay prices above GH₵ 100.00 This perhaps, was because Non-Governmental Organizations (NGOs) organized seminars on *Sargassum* for the farmers in the Western region hence they were aware of its importance. No wonder farmers offered the highest price of *Sargassum* compost (GH₵ 420.00) in the Western region (Table 4.23).

Reasons for choices of prices farmers are willing to offer for *Sargassum* compost

In the Volta region, the second highest majority of these farmers reported that until they tested the *Sargassum* compost on crops, they would not be able to pay high price. This assertion by farmers perhaps, was because many doubted the efficacy of

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organic fertilizers. However, many farmers in the three regions believed that the *Sargassum* compost would be a good one full of nutrients, which was an indication and assurance to the researcher.

Preference of texture of *Sargassum* compost by farmers

Apart from the Volta region, where the minority of the farmers (12 farmers) responded that they preferred the powdered form of the *Sargassum* compost to the granular form, most farmers in Western and Central regions preferred the *Sargassum* compost in the granular form. The request of these farmers was in the right direction because most organic manures such as compost were always in the granular form.

Conclusion

It is concluded that farmers used organic manure such as compost, farmyard manure, faecal sludge, cattle manure, poultry droppings and artificially manufactured organic fertilizer to produce crops. Farmers understood the value of organic manure as well. Furthermore, farmers were aware of the constraints of organic manure with bulkiness of organic manure being ranked as their largest limitation. Truly the transportation of these organic manure to their destination increased production cost of crops. Furthermore, farmers could link the organic manure to the *Sargassum*-based compost to know that it would benefit them. The farmers were also willing to accept and buy the *Sargassum*-based compost.

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CHAPTER FIVE

COMPOSTING SARGASSUM AND QUALITY OF THE COMPOST

Introduction

Compost is a fertilizer made from a combination of organic waste and decomposing plants. Composting on the other hand, is a process of converting a heterogeneous organic material into more homogenous fine particles and humus-like material through controlled biological oxidation process (Dougherty, 1999). The organic waste is broken down by bacteria and fungi aerobic saprotrophic organisms (Martin & Hine, 2008). The biochemical activities of biotic components such as microbial populations are the main factors influencing compost decomposition (Steger *et al.*, 2005; Ruggieri *et al.*, 2009; Sharma *et al.*, 1997).

According to Onwosi *et al.* (2017), three distinct phases of the composting process existed and these include the mesophilic phase (beginning), the thermophilic phase (middle), and the maturation phase (end). These phases have different physico-chemical properties such as plant-accessible nitrogen (N), temperature and microbial populations (Barthod *et al.*, 2018).

Much research has been done to understand the complexity of chemical and physical changes that occur at each phase of the composting process in order to enhance and produce a product suitable for use in agriculture downstream (Oviedo-Ocaña *et al.*, 2019; Nafez *et al.*, 2015). For example, in the composting process starting material properties such as the proportions of carbon (C) to nitrogen (N) in feedstocks are known not only to affect transformations of the composting process, but also the properties of the final compost product (Bernal *et al.*, 1998; Mathur *et al.*, 1993; Warmen, 1999).

Composting an upgraded soil increases soil fertility and strengthens the structure of the soil, which increases its water-holding capacity and reduces runoff (Rynk, 1992).

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Sargassum-based fertilizers have been shown to boost crop yield in various agricultural production systems (N'Yeurt & Less, 2014; Crouch & van Staden, 1993). However, there is limited information on using sawdust biochar, poultry manure and *Sargassum* to produce compost in Ghana. The study examined the entire composting process, starting from the feedstock's combination to the compost's maturity quality.

Objectives

1. To assess the *Sargassum* spp. composting process and phases during feedstock decomposition and compost quality characteristics.

2. To evaluate the use of sawdust biochar in improving decomposition of compost and nitrogen transformation during composting.

Hypotheses

Ho: The chemical properties of the phases of composting are the same.

H_1: The chemical properties of the phases of composting are not the same.

Ho: The chemical properties of the product quality of *Sargassum* spp. compost are the same.

H_1: The chemical characteristics of the product quality of *Sargassum* spp. compost are not the same.

Ho: Sawdust biochar does not improve the decomposition and nitrogen transformation during composting.

Hi: Sawdust biochar improves the decomposition and nitrogen transformation during composting.

Materials and Methods

***Sargassum* spp. collection and preparation**

To confirm that mineral resources like potassium, phosphorus and nitrogen were present in *Sargassum* spp. the feedstock was collected from Cape Coast, Elmina,

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Shama, Akwidaa and Dixcove beaches after permission was sought from Environmental Protection Agency (EPA) authorities in these areas. The 50 kg jute sacs containing the *Sargassum* spp were then delivered to the School of Agriculture Teaching and Research Farms at the University of Cape Coast, where they were air-dried. A heap of the *Sargassum* spp. is shown in Figure 5.1. A portion of the material was removed and dried in a 65°C oven for 72 hours. The materials were milled afterwards to pass through a 2 mm sieve. After putting them in three replicates in zip lock polythene bags, the materials were taken to the University of Ghana's Soil Science laboratory for pre-chemical analysis. The materials were assessed for nitrogen, phosphorus and potassium using the Kjedahl digesting method along with other factors like pH, electrical conductivity, total carbon and organic matter in accordance with the guidelines given by Okalebo, Cuthua & Woomer (2002).



Figure 5.1: A heap of collected *Sargassum* spp. being air dried in School of Agriculture Teaching and Research Farms before chemical analysis

Poultry manure and sawdust collection and preparation

With approval from the Farm Manager, poultry manure was removed from the School of Agriculture Teaching and Research Farm. The poultry manure was put into 50 kg jute sacks, kept at room temperature and later taken for laboratory analysis.

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Sawdust and wood shavings were also obtained from the 'Nyame Ndae' (translated as God is not asleep) sawmill factory at Kakumdu, Cape Coast. They were transported to the School of Agriculture Alexander G. Carson Technology Centre for sun-drying. After drying, they were bagged and stored for biochar preparation.

Sawdust biochar preparation

Sawdust was used to make the biochar that was employed in the study. The sawdust and wood shavings used to light the sawdust were dried for two weeks to reduce their moisture content. The sawdust biochar was prepared with the ELSA barrel (Steiner *et al.,* 2018) at an average temperature of 380^{O}C, determined using an infra-red Laser radiation thermometer (Omegascope, USA). A description of the ELSA barrel has already been published in the literature (Steiner *et al*., 2018). Following four hours of the biochar's pyrolysis, the barrel's contents were emptied onto an iron sheet, dossed with ample water and vigorously swirled to avoid ash formation. The biochar was then air-dried, packaged and kept at a room temperature for compost production.

Co-compost biochar and compost preparation

Biochar made from sawdust, one-and-a-half-month-old poultry manure and the windrow method of composting was combined with *Sargassum* spp. to create co-composting (Yvette & Holmer, 2000). Four different composts were prepared: *Sargassum* spp. without poultry manure and biochar, another with compost made up of *Sargassum* spp. and poultry manure and two of the composts made up of *Sargassum* spp. poultry manure and sawdust biochar. The bulking percentages for the feedstocks were established to enable the composting process to start using the Cornell University composting formula. The bulking percentages of *Sargassum,* poultry manure and biochar were 50:25:25 for compost one and 50:40:10 for compost two, respectively. In

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composts three and four, the bulking percentages were 50:50 for *Sargassum* spp. and poultry manure and 100 for only *Sargassum* spp. respectively.

The materials were fully mixed with water using a pitchfork after they were weighed using Radwag Electronic Balance [(RADWAG Wagi Elektroniczne, Poland (EU)]. With the aid of a moisture probe, Acclima Digital True TDR-315H Sensor (Aclima, Inc. Idaho, USA), the compost's moisture content was kept between fifty and sixty percent. A thick layer of black polythene rubber covered the bulky materials. Turning was done every three days. Temperature readings were taken using an Instant Read Pocket Thermometer. Figure 5.3 depicts the graph that shows the compost's average temperature at each turning. A moisture probe was used to take the moisture level of the compost when it was turned. Samples of the compost were taken every time it was turned and kept in the refrigerator for storage before the determination of the rate of decomposition of the compost.

Later on, 3 of the refrigerated stored compost samples were chosen based on the compost temperature graph drawn to test for pH, total N, total C, NH_4^+-N, NO_3^--N and EC to measure the compost's rate of breakdown in order to identify the phases of the composting process such as mesophilic, thermophilic and cooling phases. The four different kinds of co-compost produced were replicated three times. When the compost had reached maturity within seven weeks, the compost pile's temperature was the same as the surrounding air's temperature. Matured co-compost and compost were randomly taken at three different locations from each heap and allowed to air-dry in order to generate a composite sample in triplicate for subsequent chemical analyses such as pH, EC, TC, TN and ammonium/nitrate ratio, available P and exchangeable K. Meanwhile, the analyses of ammonium nitrogen and nitrate nitrogen were done fresh without air-drying the samples. The matured compost is represented in Figure 5.2.

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Figure 5.2: Matured compost 1, 2, 3 and 4 and their proportions

Digestion of feedstock and compost materials

The mixture of the digestion contained 420 mL of sulphuric acid, 0.42 g of powdered selenium, 14 g of lithium sulphate and 350 mL of hydrogen peroxide 0.1 to 0.4 g of the ground oven-dried samples were weighed into a 100 mL Kjeldahl flask and 4.4 mL of the mixed digestion reagent was added, in accordance with the protocol of Stewarte *et al.* (1974). The plant sample was allowed to completely dissolve in the sulphuric acid by leaving the flask alone for the entire night. Analogously, digestions of the digestion mixture without a sample known as blank digestions, were carried out.

Aliquots of the digest or extract were taken to determine phosphorus, potassium and nitrogen after each solution had been heated for two hours at 360°C and hydrogen peroxide had been added until a clear solution was visible. After adding distilled water, letting the mixtures cool and filtering them into 100 mL volumetric flasks, they were then filled to the 100 mL mark for additional analysis.

Biochar, *Sargassum* spp. and poultry manure analysis

pH determination of feedstock

A 50 mL centrifuge tube was filled with ten (10) g of compost that had been weighed twice. A 1:2.5 compost-to-water solution was made by combining each sample

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with 25 mL of distilled water (Page *et al.*, 1982). For 15 minutes, the centrifuge tubes were shaken mechanically to mix the feedstock completely. A Jenway 3330 Research pH meter (Jenway Ltd, Felsted, Dunmow, Essex, CM6 3LB, UK) was used to measure the pH of each suspension. (Page *et al.*, 1982). Three replications of each biochar, *Sargassum* spp. and poultry manure measurements were made.

Total carbon determination of feedstock

The ashing technique was applied, as described by Mclaughlin (2010). Three identical 5g ± SD feedstock samples were placed in a ceramic crucible that had been previously weighed. After that, the crucibles were placed in a furnace that had been warmed to 550°C and the ashing process was left to run a whole night. After cooling, the masses of each crucible and the ashes were measured and weighed. Each sample underwent this measurement three times. The following formula shown below was used to compute total carbon.

$$\%C = \frac{W2-W3}{W1-W3} \times 100 \quad \text{.....[5.1]}$$

Where:

W_1= biochar's wet weight, *Sargassum* and poultry manure and porcelain crucible (grammes)

W_2= biochar's dry weight, *sargassum* and poultry manure, porcelain crucible (g)

W_3= porcelain weight (g)

Feedstock total nitrogen determination using the Micro-Kjeldahl method

A 0.2 g feedstock sample was digested in a Tecator Digestor 2012 utilizing a concentrated H_2SO_4-H_2O_2 combination. A blank digest was also finished. The digest was reduced to 25 mL by distilling it into conical flask measured 100 mL with 2% boric acid. In comparison to a 0.0071 M HCL, the distillate was titrated from green to pink. The formula used to calculate the total N content was as below:

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%N= (S-B x T) x14 x 5 x 100/200 ……[5.2]

Where:

S= volume of 0.007MHCL used for sample titration

B= volume of 0.007MHCL used for sample titration

T= molarity of HCL

14 = atomic weight of nitrogen

5 = sample dilute factor

200 = sample weight in mg

100 = factor for %

Total phosphorus determination

In this instance, ascorbic acid technique was used. For every instance, three duplicates were created. A hundred mililitres (100 mL) conical flasks were filled with the washed digestate and its contents. An operational standard of 5 g P mL^{-1} (ppm) was produced using a 100-ppm stock solution of P. Using 5 g of P mL^{-1}(ppm) working standards, volumes of 0.5 mL, 1 mL, 2 mL, 3 mL, 4 mL and 5 mL were combined with 4 mL of reagent B in a 25 mL volumetric flask. These volumes were then utilized to produce 0, 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 ppm of P. Distilled water was applied to its mark after some time. For the solution to turn blue, it was left to stand for fifteen minutes. 1 mL of aliquots for each sample were pipetted into individual 25 mL volumetric flasks and 4 mL of reagent B, a mixture of potassium antimony tartrate and ammonium molybdate in ascorbic acid was then added. After that, distilled water was added to the sample aliquot until the appropriate volume was reached. For fifteen minutes, the solutions were let to stand, enabling the blue colour to emerge. The phosphorus amounts in the samples and working standards were determined using a spectrophotometer. Before reading, the spectrophotometer (Spectronic 20) was warmed

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for 20 minutes. It was then calibrated using the 0-ppm blank standard. The working standards and the sample readings were then read at a wavelength of 880 nm. Using Microsoft Office Excel 2007, graphs of absorbance against concentrations were produced. This makes it possible to determine the sample concentrations and establish the linear relationship: y= 0.714x +0.006, where x is the concentration of P in solution represented as µg mL^{-1} or ppm and y is the absorbance in percent. The final P concentrations in the digestate of the respective samples were estimated using the following equations:

Ppm (ppm or µg mL^{-1}) =Ppm of P in solution x $\frac{vol\ of\ extractant(ml)}{weight\ of\ feedstock(g)}$ ×

$\frac{final\ volume\ of\ aliquot\ (mL)}{initial\ vol\ of\ aliquot\ pippetted(mL)}$ … … … … … … … … … … [5.3]

Total potassium determination

Potassium was measured using the H_2SO_4-H_2O_2 digest in accordance with Stewarte *et al.* (1974) procedures. The flame was allowed to settle for half an hour, while potassium standards were used to calibrate the flame photometer before the reading was taken. The K concentration was determined using the flame photometric technique. Every reading was captured in three duplicates. After that, a flame photometer was used to measure 100 mL of the contents and three readings were taken. The following formula was used to calculate the final concentration of K in the solution of the respective samples:

%K= C/100 x wt…….. [5.4]

Where;

C = concentration of potassium from emission curve (%)

Wt = weight of soil in grammes, g

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Iron, copper and zinc determination of using atomic absorption spectrophotometer

Following feedstock digestion, standard solutions of Fe, Cu, and Zn at 1, 2 and 5µg/mL were made. The Atomic Absorption Spectrophotometer (AAS) (VVVR International, Research Park Haasrode 2020, Geldenaaksebaan 464, B-300 1Leuven, China) was aspirated with the standard solutions, and the corresponding calibration curves were drawn on the AAS. The concentrations of the sample solutions were given as they were aspirated. The formula for determining Fe, Cu and Zn was calculated as below:

$$\text{Fe (µg/g)} = \frac{C \; x \; solution \; volume}{Sample \; weight} \quad \text{.....[5.5]}$$

$$\text{Cu (µg/g)} = \frac{C \; x \; solution \; volume}{sample \; weight} \quad \text{.....[5.6]}$$

$$\text{Zn (µg/g)} = \frac{C \; x \; solution \; volume}{sample \; weight} \quad \text{.....[5.7]}$$

Characterisation of compost

Determination of compost pH

The same process used for the feedstock above was used to determine the pH of the compost.

Iron, copper and zinc determination using atomic absorption spectrophotometer

Using an atomic absorption spectrophotometer, the composition of iron, copper and zinc in the compost was determined by using the same protocol as for the feedstock mentioned above.

Total organic carbon determination

The guidelines of Stewarte *et al.* (1974), a traditional laboratory method to ascertain the compost's total organic carbon content was followed in order to determine organic carbon using the Walkley-Black method. Next, a 500 mL Erlenmeyer flask was filled with 0.2 g of 2 mm sieved compost samples. The flasks received 10 mL of

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potassium dichromate ($K_2Cr_2O_7$) solution and were gently swirled for 30 seconds. Immediately, 20 mL of concentrated sulphuric acid (H_2SO_4) was added after swirling, and one minute was spent swirling. The mixture was left to stand for half an hour. To dilute the contents of each flask, 200 mL of distilled water was added. One diphenylamine sulphonate indicator was added to the solution in the flask after ten millilitres of orthophosphoric acid. The excess $K_2Cr_2O_7$ was back-titrated using 0.5 M ferrous solution once it reached a green endpoint. The process for handling blank solutions was the same. The following formula was used to determine the compost's proportion of organic carbon:

$$\text{O.C (\%)} = \frac{(B-S)x\ Molarity\ of\ Fe(II)x0.003}{Weight\ of\ compost(g)}\ x\ \frac{100}{77}\text{x}100 \quad \text{[5.8]}$$

Where:

S= sample titre value, mL

B = blank titre value, mL

0.003 =12/4000 = milli-equivalents weight of carbon, mg

100/77 = the factor that changes oxidized carbon into total carbon

100 = the conversion factor from oven dried soil weight (g) in decimal to percent

Determination of total nitrogen

Using the Micro Kjeldahl method as published by Page *et al.* (1982) the total nitrogen content of the compost was ascertained. The compost weighed around 0.2 g in triplicate into individual Kjeldahl digestion flasks. After adding around 1.1 g of the catalyst combination, 3 mL of concentrated H_2SO_4 were added. The flasks were heated to 360°C for two hours on a digester. Once a clear digest was produced, the flasks were taken out and allowed to cool. After cleaning it with distilled water, the digest was poured into a 50 mL conical flask and filled to the top. After pipetting a twenty (20) mL aliquot of the digest, 10 mL of NaOH were added to the distillation unit. A 100 mL

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conical flask with 5 mL of boric acid (H_3BO_3) indicator was placed underneath the distillation unit's funnel in order to collect 50 mL of the distillate. To get a wine colour, the distillate was titrated against a 1/140 M HCL solution. Using the following formula, the nitrogen content of the compost was determined:

$$\%N = \frac{(S-B)X\ Solution\ volume}{100\ x\ volume\ of\ aliquote\ x\ weight\ of\ compost} \quad \text{.....[5.9]}$$

Where S = sample titre value (mL)

B = blank titre value (mL)

Determination of available nitrogen content of compost

The procedure to ascertain the available nitrogen concentration in the compost was determined (Bremner, 1965). Ten grams (10.0 g) of the 2 mm sieved sample and fifty millilitres of 2 M KCl were added to a 100 mL extraction container. A blank was added that was devoid of compost. After shaking the compost suspension for 20 minutes, it was filtered using No. 42 Whatman filter paper and placed in a clean storage bottle. A 250 mL Kjeldahl flask containing a 10 mL aliquot of the filtrate was filled with 0.2 g of MgO powder. The magnesium oxide was desiccator-cooled and oven-dried before use. Ammonia was distilled into 5 mL of 2% boric acid using a 150 mL conical flask along with a methylene blue and methyl red indicator combination. After the solution in the 250 mL Kjeldahl flask cooled, 1 mL of 0.2 M sulphuric acid was added to remove the nitrite from the sample. It took exactly 0.2 g of Devarde's alloy to change NO_3^--N into NH_4^+-N. Again, the distillate was collected with 5 mL of a 2% boric acid indicator mixture in a separate conical flask. A 0.01 M HCL was used to titrate the distillates. For each of the individual titre values, the below formula calculates the NH_4^+ concentration (mg kg-^{1}):

$$NH_4^+//NO_3\ (\text{mg kg}^{-1}\text{compost}) = \frac{M_{HCl} \times V_{HCl} \times 14 \times V_{KCl} \times 10^3}{\text{The volume of aliquot} \times \text{weight of soil}} \quad \text{..... .[5.10]}$$

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Where:

M_{HCl} = Molarity of the HCl

V_{HCl} = Titre of the HCl

V_{KCl} = Volume of KCl extractant

14 = Molecular weight of N

The values for the two separate calculations were summed up as available N.

Determination of cation exchange capacity (CEC)

The $BaCl_2$/Triethanolamine (TEA) solution buffered at pH 8.2 was used to measure the compost's cation exchange capacity. A 40 mL of 0.2 M $BaCl_2$-TEA solution was added to two grams of compost sample, which had been weighed in 100 mL plastic bottles. The suspension was initially filtered through a 0.45 µm filter paper after being shaken for an hour in a reciprocating shaker. The compost residue was collected in an empty plastic container and then leached using four volumes of a 10 mL, 0.1 M $MgSO_4.7H_2O$ solution. The leachate was collected in another clean plastic bottle. An atomic absorption spectrophotometer was used to measure the amount of Ba^{2+} in the leachate and the CEC of the compost was computed as follows:

$$CEC\ (\text{cmol}_c\text{kg}^{-1}) = \frac{\text{AAS reading } (\mu\text{g mL}^{-1}) \times 40\text{ mL} \times 10^3\ (\text{g}) \times 10^2(\text{cmol}) \times 2}{\text{Weight of biochar (g)} \times 10^6 \times 137.3} \quad \ldots\ \ldots\ \ldots\ \ldots [5.11]$$

Where 137.3= Molar mass of Barium

Determination of total phosphorus

The digest was pipetted into 25 mL test tubes with flat bottoms in a 2 mL aliquot. Reagent B, a colourant-forming agent was added to the flask in 4 mL. The solutions were topped off with distilled water to reach the 25 mL threshold. After 15 minutes of standing time for colour development, the test solutions absorbance was read at 882 nm using a spectrophotometer (CE 1000 series). From a 5 g P mL^{-1} stock solution, working solutions containing 0.0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 g P mL^{-1} were made. A

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spectrophotometer (CE 1000 series) was used to measure the absorbances of the working solutions at 882 nm after the blue colour had developed for 15 minutes. The amount of P in the compost was ascertained using the standard calibration curve.

Available phosphorus determination

Olsen's P method (Olsen & Dean (1965) was used to determine the amount of available phosphorus in the compost. One gram of compost and 100 mL of 0.5 M $NaHCO_3$ (pH = 8.5) were carefully weighed and placed into an extraction vial. As a blank for the analysis, an additional 100 mL of the 0.5 M $NaHCO_3$ were dispensed into an empty 100 mL extraction vial. After a vigorous 30-minute shake on a mechanical shaker, the bottle and its contents were filtered through No. 42 Whatman filter paper to remove the supernatant. Immediately, a 15 mL centrifuge tube was filled with 5 mL of 5 N H_2SO_4 and an aliquot of 1 mL. The centrifuge tube and its contents were refrigerated for approximately half an hour. After centrifuging the tube for 15 minutes at 8500 rpm, the supernatant was poured into a 50 mL volumetric flask. Next, using a PU 8620 UV/VS/NIR spectrophotometer calibrated with a standard P solution, the amount of compost accessible phosphorus was ascertained (Olsen & Dean, 1965).

Determination of available cations (K^+, Ca^{2+}, Mg^{2+} and Na^+)

A 50 mL centrifuge tubes were filled with 0.5 g of compost sample. After adding 20 mL of ammonium acetate (NH_4OAc) solution and stirring it for an hour, it was allowed to stand overnight. Whatman filter paper No. 42 was used to line 100 mL conical flasks with the suspension. The compost residue trapped on the filter paper was gradually leached with 20 mL of the NH_4OAc solution until 100 mL of the filtrate were obtained. From the filtrate, the cations K^+, Ca^{2+}, $Mg^{2+,}$ and Na^+ were separated and identified. EDTA titrimetry was used to quantify calcium and magnesium, while a flame photometer was used to estimate the concentrations of Na and K ions.

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Exchangeable K^+, cmolc kg^{-1} compost = $\frac{C\ X0.256}{Weight\ of\ compost(g)}$..... [5.12]

Exchangeable Na^+, cmolc kg^{-1} compost = $\frac{C\ x\ 0.44}{Weight\ of\ compost\ (g)}$..... [5.13]

Exchangeable Mg^{2+}, cmolc kg^{-1} compost = $\frac{4\ xT}{Weight\ of\ compost\ (g)}$..... [5.14]

Exchangeable Ca^{2+}, $cmol_c$ kg^{-1} compost = $\frac{4\ x\ T}{Weight\ of\ compost(g)}$..... [5.15]

Where C =concentration from a calibration curve

T = titre value

Determination of calcium and magnesium by EDTA titrimetry

A 25 mL portion of the filtrate was transferred into a 250 mL Erlenmeyer flask. The solution was diluted to 150 mL with distilled water and then 15 mL of buffer solution were added. The solution was supplemented with 1 mL volumes of KCN, NH_2OH, HCl, $K_4Fe\ (CN)_6$ and TEA. Ten drops of EBT indicator were added to the resultant solution and it was titrated against a 0.005 M EDTA disodium solution after standing for five minutes.

Determination of calcium by titrimetry

A 25 mL aliquot of the filtrate was transferred to a 250 mL Erlenmeyer flask and diluted to 150 mL with distilled water. The compost extract was mixed with one millilitre each of KCN, NH_2OH, HCl and TEA (triethanolamine) and then 20 millilitres of 10% NaOH was added. A 0.005 M EDTA solution was used to titrate ten drops of the calcon indicator from the red to a blue endpoint. By aspirating the sample using flame photometry, total K and accessible Na in compost were calculated (Page *et al.*, 1982).

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Compost electrical conductivity (EC) determination

The same supernatant that was used to determine the pH of the water was used to determine the EC of the compost. A standard 0.01 M KCl solution was utilized for the electrical conductivity meter's initial calibration. To evaluate electrical conductivity, the conductivity electrode was put into the supernatant and the resultant value was recorded.

Determination of NH_4^+-N and NO_3^--N

After adding 5 g of the compost and 50 mL of 2 M KCL, everything was well agitated for 30 minutes or until the clear supernatant was obtained. After taking an aliquot, it was allowed to settle. A 5 mL aliquot was taken and added to the Kjeldahl distillation tube. On the Kjeldahl distillation equipment, around 0.2 g of magnesium oxide was introduced and distilled. Over five millilitres of boric acid, the NH_4^+-N distillate was collected. To the same sample, 1 mL of 2% sulphuric acid was then added. Also, 0.2 g of Devardes alloy was added, and the mixture was distilled once more. The assortment turned into NO_3^--N.

Determination of total calcium, magnesium, sodium and potassium

A 5 mL of sulphuric acid and 0.1 g of weighed compost were combined in a 50 mL conical flask. After that, the mixture was allowed to stand for six hours, preferably overnight. The mixture was next cooked on a hot electric plate. Next, 1 mL of hydrogen peroxide was constantly added until a clear solution was reached. After extracting the resulting solution into a 100 mL volumetric flask, it was measured with a flame photometer or an AAS.

Calculation:

$$\%(\text{Ca, Mg, Na and K}) = \frac{Machine\ readings\ x dilution\ factor x\ volume\ of\ extract}{Weight\ of\ sample\ x\ 1000(g) x\ 100} \ldots [5.16]$$

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Statistical analysis

To ascertain the significance of the data, general analysis of variance (ANOVA) was carried out using GenStat Twelfth Edition, Procedure Library Release PL20.I, 2009 (VSN International Limited, Rothamsted Experimental Station, Hemel Hempstead, UK). Fisher's Protected Least Significant Difference test with 5% probability and Tukey's Honestly Significance Difference (HSD) were used to separate the means. The data were represented graphically using Microsoft Excel.

$$y_{ij} = \mu + f_i + r_j + \varepsilon_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [5.17]$$

Where: y_{ij} = observation from the i^{th} feedstock and j^{th} replication, μ = overall mean, f_i = effect of the i^{th} feedstock, r_j = effect of the j^{th} replication, and ε_{ij} = the experimental error.

Results

Chemical characteristics of compost feedstock

The pH of the *Sargassum* spp. poultry manure and sawdust biochar were all alkaline (*Sargassum* spp.= 7.27±0.1, poultry manure =7.91±0.0 and biochar =9.58±0.2). Poultry manure had the highest organic carbon (29.84 ±1.3%), followed by *Sargassum* spp. (26.66 ±1.9%) and biochar (2.67 ± 0.3%). Total nitrogen (N) for Poultry manure was highest (1.76 ±0.1%), followed by *Sargassum* spp. (1.11±0.1%) and biochar (0.30 ±0.1%). The total phosphorus of Sargassum spp. was 0.11±0.0% and that of poultry manure was 0.99 ± 0.1%. (Table 5.1). Biochar had the highest carbon-to-nitrogen ratio (123.9 ±23.5), followed by *Sargassum* spp (26.6 ±0.5) and poultry manure (17.0 ±1.2). The total phosphorus for biochar was 0.06±0.1%. Furthermore, the total potassium of *Sargassum* was 3.04±0.1% while the total potassium for poultry was 0.92 ±0.0%. Biochar had a total K content of 0.50±0.0%. On the other hand, for moisture content of

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the feedstock, biochar had the highest (51.82 ±0.2%), followed by poultry manure (12.33 ±0.4%) with *Sargassum* spp. recording (11.03± 0.4%). The total Zn, Cu, Fe and B for *Sargassum* spp. were 0.04±0.0%, 0.02±0.0%, 0.08 ± 0.0 and 77.47 ±0.2 µg/g, respectively (Table 5.1).

Table 5.1: Chemical characteristics of compost feedstock

	pH	EC	OC	TC	TN
Feedstock		µS/cm	%		
Sargassum spp.	7.27±0.1	38.33±5.0	26.66±1.3	29.61±0.3	1.11±0.1
Poultry manure	7.91±0.0	7.50±0.2	29.84±1.9	29.90±0.1	1.76±0.1
Biochar	9.58±0.2	0.73±0.1	2.67±0.3	37.04±0.4	0.30±0.1

Table 5.1 Continued

	C:N	P	K	MC
Feedstock			%	
Sargassum spp.	26.6±0.5	0.11±0.0	3.04±0.1	11.03±0.4
Poultry manure	17.0±1.2	0.99±0.1	0.92±0.0	12.33±0.4
Biochar	123.9±23.5	0.06±0.0	0.50±0.0	51.82±0.2

C:N= Carbon to nitrogen ratio, P=Total Phosphorus, K=Total Potassium, MC=Moisture content

Table 5.1 continued

	Zn	Cu	Fe	B
Feedstock		%		µg/g
Sargassum	0.04±23.5	0.02±23.5	0.08±23.5	77.47±23.5

Zn =Zinc, Cu, = Total Copper, Fe =Total Iron, B =Total Boron

Composting phases during composting

Mesophilic phase

Compost temperature began to rise within the 3rd day of composting with compost 1 (50:25:25) and compost 2 (50:40:10) attaining temperatures of 39ºC

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and 38°C, respectively, while compost 3 (50:50) and compost 4 (100 *Sargassum*) attaining a temperature of 37°C. The mesophilic phase lasted for seven days and on that day, temperatures rose to 49°C for compost 1, compost 2 (47°C) compost 3 (45°C) and compost 4 for 48°C (Figure 5.3).

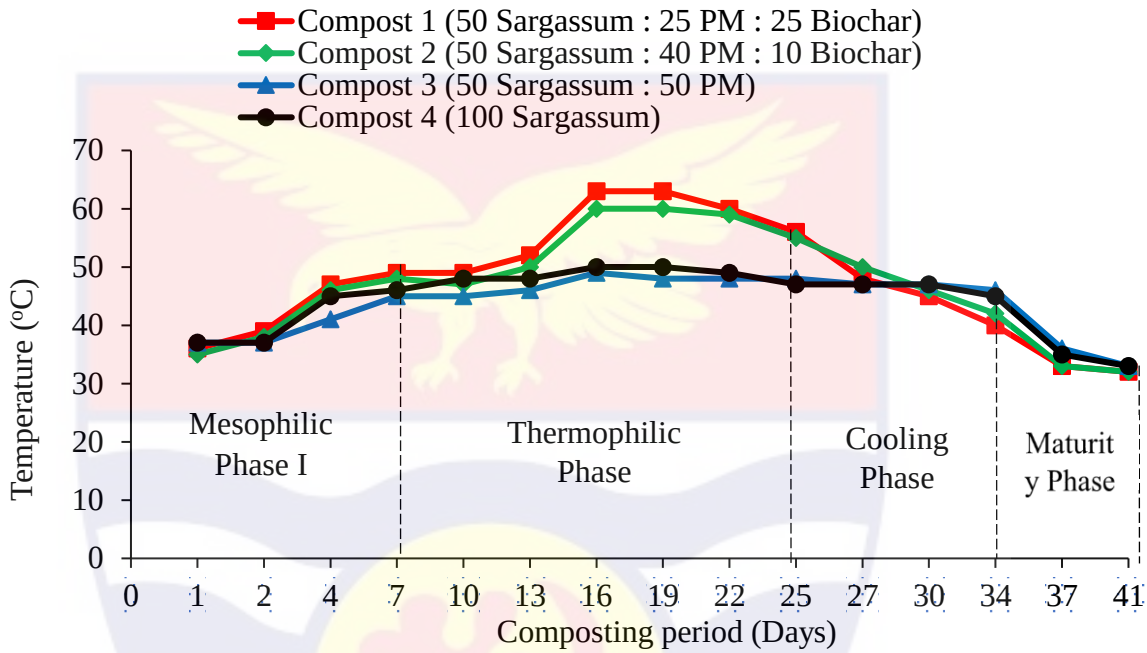


Figure 5.3: The temperature dynamics during the the four different kinds of compost production process

Thermophilic phase

The composts hit the thermophilic phase on day 13 for all composts with temperatures of 52°C, compost 1(50:25:25), 50°C for compost 2(50:40:10), 46°C for compost 3 (50:50) with compost 4(100 *Sargassum*) being 48°C. This means compost 1 had a 4% increase in temperature over compost 2. Compost 2 also had an 8.7% increase in temperature over compost 3. On day 16 of the composting process, the temperatures of composts 1, 2, 3 and 4 were the highest measuring 63°C, 60°C, 49°C and 50°C, respectively. The thermophilic phase lasted for 12 days (Figure 5.3).

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Cooling phase

The cooling phase of the compost production process started from day 25 up to day 34. During this phase, temperatures started dropping for the compost as follows: compost 1 (50:25:25) attained 56^{o}C, compost 2 (50:40:10) attained 55^{o}C, compost 3 (50:50) attained 48^{o}C and compost 4 attained 47^{o}C. Compost 1 and 2 expressed a rapid decline in temperature, recording 40^{o}C and 42^{o}C, respectively lower than compost three and compost four, which recorded 46^{o}C and 45^{o}C on day 34 (Figure 5.3).

Maturation phase

During this phase, the temperature dropped further for the four composts. From Figure 5.3, it was clear that temperature of composts 3 and 4 remained high, although they were dropping compared to compost 1 and compost 2. For example, on day 37, compost 1 (50:25:25) and compost 2 (50:40:10) recorded temperature values of 33^{o}C whilst compost 3 (50:50) and 4 (100 *Sargassum*) recorded 36^{o}C and 35^{o}C, respectively, indicating earlier maturity of compost one and compost two than compost three and compost 4. Temperature reduction occurred again on day 41 with values of 32^{o}C for composts 1 and 2 and 33^{o}C for composts 3 and 4. This temperature continued to reduce further, and as soon as the compost temperatures were equivalent to room temperature, it meant the compost was matured and it could be air-dried for two weeks before sampling for laboratory chemical analysis.

Effect of feedstock decomposition on pH

Significant differences (P=0.01) were noticed in pH during the mesophilic, thermophilic and cooling phases during the composting process (Figure 5.4). On the third day of the compost sampling during the mesophilic phase, compost 1 (50:25:25), compost 2 (50:40:10) and compost 3 (50:50) were all slightly basic, obtaining the highest pH value of 7.8, except compost 4 (100 *Sargassum*), which was slightly acidic

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recording the pH value of 6.5 (Figure 5.4). On day 16 during the thermophilic phase, compost 1 (50:25:25) and compost 2 (50:40:10) had the highest pH of 7.9 an increase of 0.1 unit from the mesophilic phase. Compost 4 (100 *Sargassum*) had the lowest pH of 6.6 which was slightly acidic, and an increase of 0.1 unit in pH from the mesophilic phase. However, on day 30 during the cooling phase, compost 1 (50:25:25) had the highest pH of 7.8, while compost 4 (100 *Sargassum*) had the lowest pH of 6.4. The pH values reduced drastically in all the four composts in this phase from the thermophilic phase (Figure 5.4).

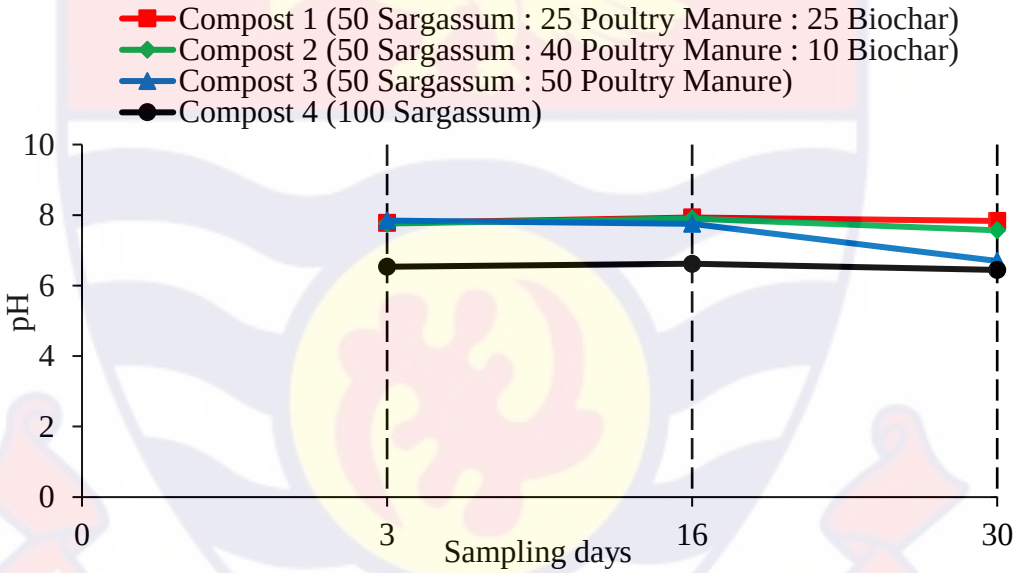


Figure 5.4: Average pH of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E. M. ANOVA established differences among sampling days.

Effects of feedstock decomposition on electrical conductivity (EC)

Significant (P=0.01) differences were seen in electrical conductivity during mesophilic, thermophilic and cooling phases of the composting process (Figure 5.5). While compost 2 (50:40:10) and compost 3 (50:50) had an EC value of 16.8 μScm^{-1}, compost 1(50:25:25) and compost 4(100 *Sargassum*) had an EC value of 16.1 μScm^{-1} and 16.7 μScm^{-1} respectively, during day 3 of the mesophilic phase (Figure 5.5). At the thermophilic phase on day 16, compost 4 (100 *Sargassum*) appeared best, obtaining the

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highest EC of 18.34 µScm^{-1} followed closely by compost 2 (50:40:10) in terms of EC (17.1 µScm^{-1}), while the lowest EC value of 15.5 µScm^{-1} was recorded by compost 3 (50:50). The four composts except compost 3 (50:50) increased in EC values from the mesophilic phase. At day 30 the highest electrical conductivity (EC) of 13.6 µScm^{-1} was recorded by compost 4 (100 *Sargassum*) during the cooling phase, while the lowest EC was recorded by compost 3 (50:50), which was 5.6 µScm^{-1}. All 4 composts saw a reduction in their EC values from the thermophilic phase (Figure 5.5).

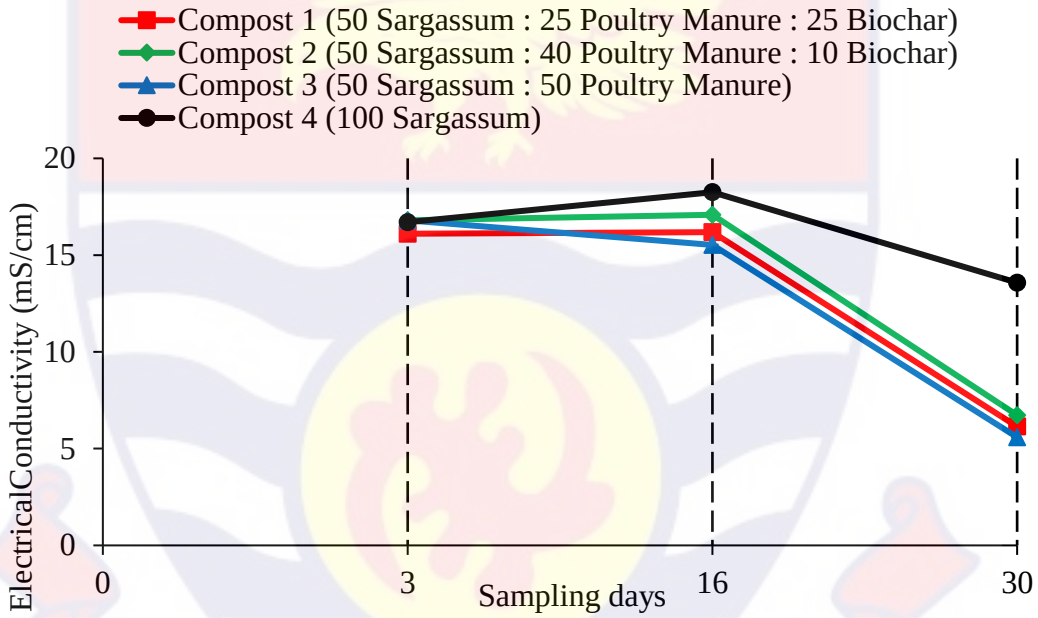


Figure 5.5: Average Electrical conductivity (EC) of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days.

Effect of feedstock decomposition on ammonium nitrogen (NH_4^+-N)

Decomposition of feedstock had significant (P=0.01) differences on the production of ammonium nitrogen during the mesophilic, thermophilic and cooling phases (Figure 5.6). Compost 2 (50:40:10) appeared best, accumulating 676 µgg^{-1} of NH_4^+-N, followed by compost 3 (50:50) accumulating 588 µgg^{-1} of NH_4^+-N. Compost 4 (100 *Sargassum*) managed the lowest NH_4^+-N of 218 µgg^{-1} during day 3 of the mesophilic phase. However, during the thermophilic phase on day 16, compost 2

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(50:40:10) accumulated the highest ammonium nitrogen of 511.0 µgg^{-1}, followed by compost 3 (50:50), accumulating 488.0 µgg^{-1}. Compost 1 (50:25:25) obtained the lowest ammonium nitrogen which was 137 µgg^{-1}. All the four compost, except compost 4 (100 *Sargassum*) decreased in their respective NH_4^+-N values from the mesophilic phase (Figure 5.6). While compost 4 (100 *Sargassum*) accumulated the highest NH_4^+-N of 344.1 µgg-^{1}, compost 2 (50:40:10) accumulated the least NH_4^+-N of 54.6 µgg^{-1} during day 30 of the mesophilic phase. All four composts except compost 4 saw a massive reduction in NH_4^+-N from the thermophilic phase (Figure 5.6).

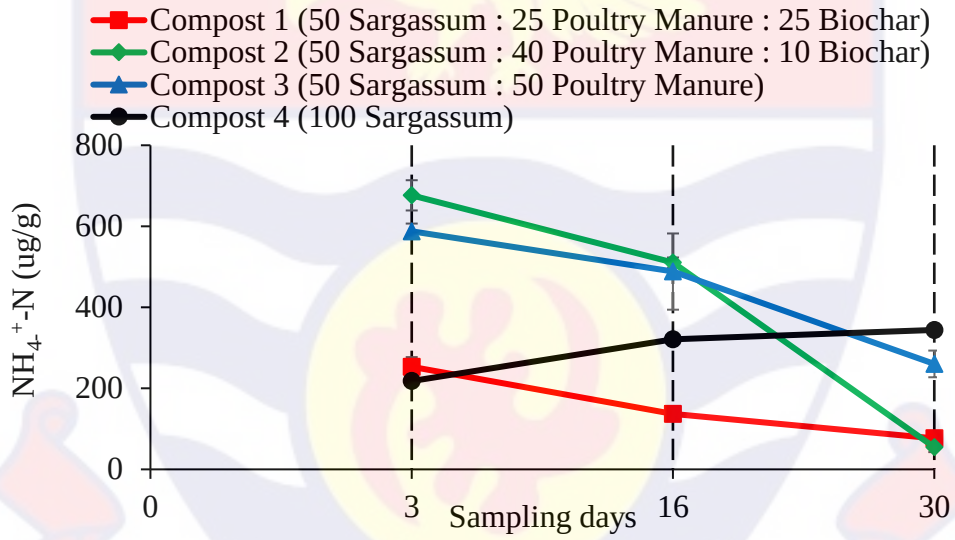


Figure 5.6: Average ammonium nitrogen of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days.

Effects of feedstock decomposition on nitrate nitrogen

Significant (P =0.01) differences were observed in the nitrate-nitrogen (NO_3^--N) content of four types of compost during the cooling phase of the composting process (Figure 5.7). During the mesophilic phase on day 3 of compost sampling, compost 2 (50:40:10) accumulated the highest nitrate nitrogen of 25.2 µgg^{-1}, whereas compost 4 (100 *Sargassum*) accumulated the lowest nitrate nitrogen of 19.0µgg^{-1} (Figure 5.7). Again, on day 16, during the thermophilic phase of the compost sampling, compost

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3(50:50) appeared best accumulating the highest nitrate N of 25.3 µgg^{-1} while the lowest NO_3^--N was accumulated by compost 1 (50:25:25), which was 19.5 µgg^{-1} (Figure 5.7). The values of compost three and compost four in terms of NO_3^--N increased from the mesophilic phase to the thermophilic phase, but the values of compost 1 and compost two declined from the mesophilic phase. While compost 3 (50:50) recorded the highest nitrate nitrogen (NO_3^--N) of 100.0 µgg^{-1} during the cooling phase on day 30 of compost sampling, the lowest NO_3^--N (24.5µgg^{-1}) was obtained by compost 4 (100 *Sargassum*) All four composts' NO_3^--N content increased as against their NH_4^+-N from the thermophilic phase (Figure 5.7).

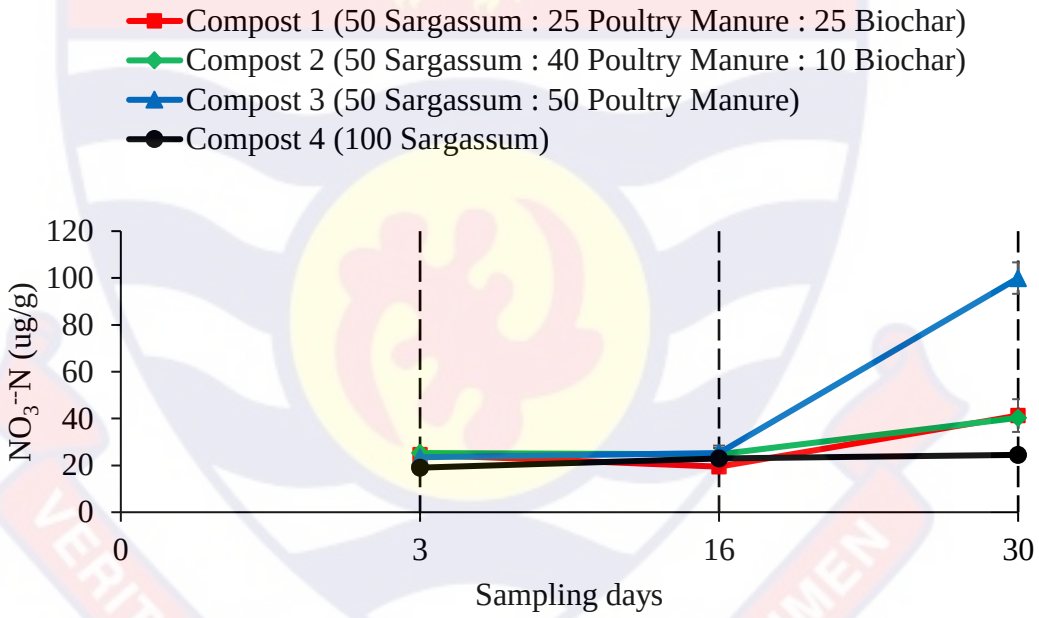


Figure 5.7: Average Nitrate nitrogen of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days.

Effects of feedstock decomposition on ammonium nitrogen-to-nitrate-nitrogen (NH_4^+-N:NO_3^--N) ratio

During the mesophilic phase of the composting process, there was a significant (P=0.01) variation in the ratio of ammonium nitrogen to nitrate nitrogen (NH_4^+-N: NO_3^--N) (Figure 5.8). Additionally, during the thermophilic phase of the composting

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process, no significant ($P<0.05$) difference existed in the ratio of ammonium nitrogen -to-nitrate nitrogen (NH_4^+-N:NO_3^--N). Compost 1 (50:25:25) recorded the lowest (NH_4^+-N:NO_3^--N) ratio of 10.3 during the mesophilic phase on day 3 of the compost sampling, whereas compost 2 (50:40:10) had the greatest ammonium nitrogen-to- nitrate nitrogen ratio of 27.2 (Figure 5.8). In contrast, compost 2 (50:40:10) recorded the highest NH_4^+-N:NO_3^--N ratio of 21.0 during the thermophilic phase of compost sampling on day 16, while compost 1 (50:25:25) obtained the lowest ratio of 7.0. Notably, composts 1, 2 and 3 showed a decrease in the values of NH_4^+-N:NO_3^--N ratio, whereas compost 4 showed an increase in the value of NH_4^+-N:NO_3^--N ratio from the mesophilic phase (Figure 5.8). Furthermore, compost 4 (100 *Sargassum*) recorded the highest NH_4^+-N: NO_3^--N ratio of 14.1, while compost 2 (50:40:10) obtained the lowest NH_4^+-N:NO_3^--N ratio of 1.4 during the cooling phase at day 30 of compost sampling. The NH_4^+-N:NO_3^--N ratio decreased in all four composts, with the exception of compost four during the thermophilic phase (Figure 5.8).

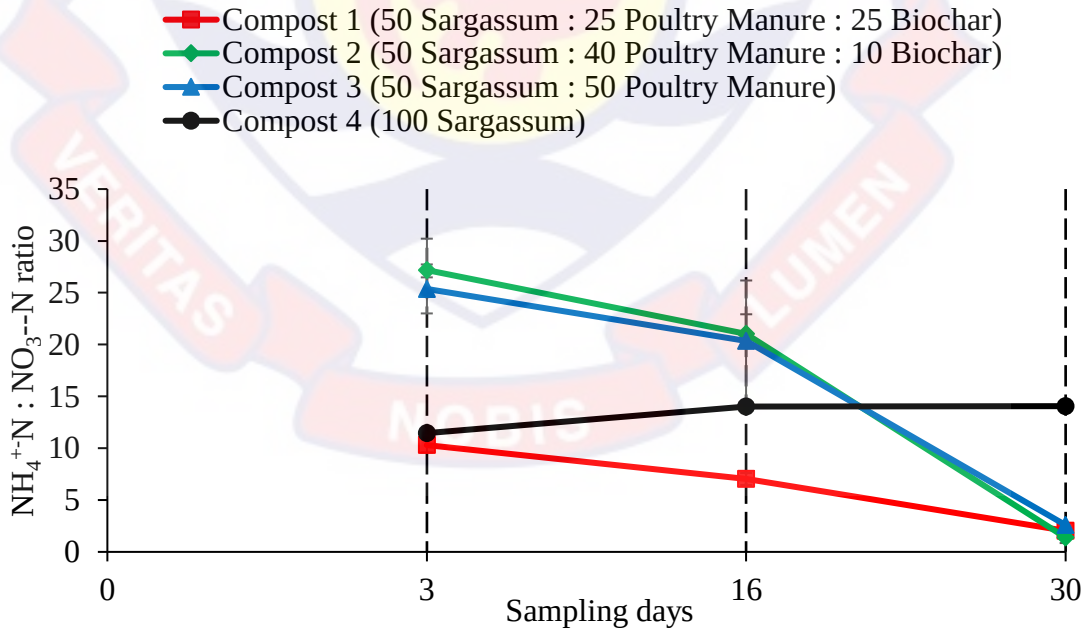


Figure 5.8: Average Ammonium N and Nitrate N ratio of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days.

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Effect of feedstock decomposition on total carbon (TC)

Significant differences (P=0.01) were found in total carbon content (TC) of the four types of compost during the mesophilic, thermophilic and cooling phases of the composting process (Figure 5.9). Compost 2 (50:40:10) appeared best, recording a total carbon content of 27.2%, while compost 3 (50:50) had the lowest total carbon of 21.6% in the mesophilic phase of compost sampling day 3 (Figure 5.9). While compost 4 (100 *Sargassum*) had the highest TC (26.2%), compost 3 (50:50) recorded the lowest TC (18.7%) during the thermophilic phase on day 16 of the compost sampling. As observed, there was a reduction in the TC values of all four composts from their respective TC values from the mesophilic phase (Figure 5.9). Furthermore, during the cooling phase, compost 1 (50:25:25) obtained the highest total carbon of 24.0%, and compost 3 (50:50) had the least total carbon (TC) of 15.2%. There was a further reduction in TC in all the four composts, except compost 1, which had an increase in TC content (Figure 5.9)

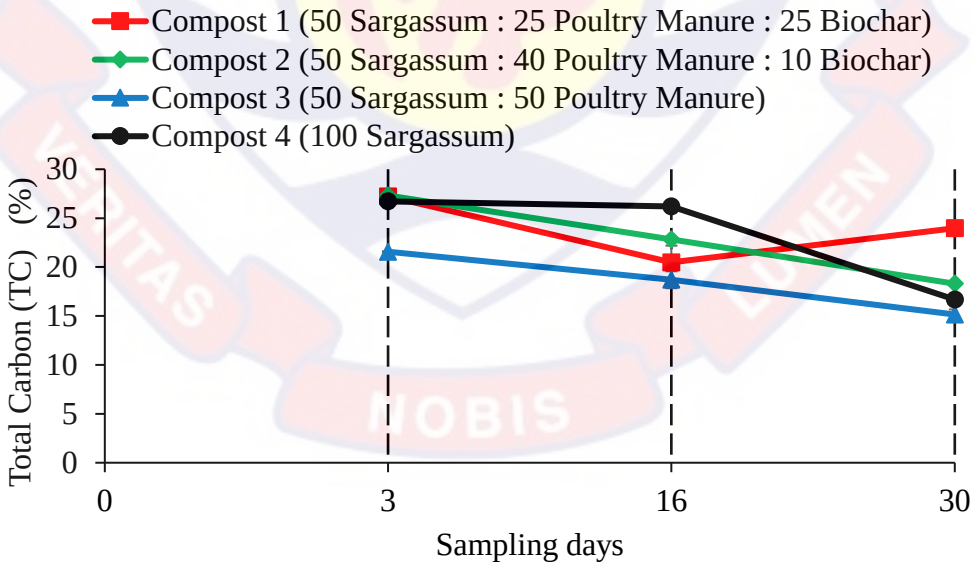


Figure 5.9: Average total carbon of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days

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Effects of feedstock decomposition on total nitrogen (TN)

During the mesophilic phase of the composting process, significant ($P < 0.05$) differences existed in total nitrogen (%N) of the four types of compost. In the thermophilic phase, no significant difference existed in total N but during the cooling phase, significant ($P = 0.01$) differences existed in total nitrogen (Figure 5.10). Compost 1 (50:25:25) accumulated the highest total N of 1.55%, while compost 4(100 *Sargassum*) obtained the lowest total N of 0.89% during the mesophilic phase on day 3 of the compost sampling (Figure 5.10). During the thermophilic phase on day 16 of the compost sampling, compost 2 (50:40:10) appeared best, accumulating the highest total N of 1.40%, while the lowest total N was obtained by compost 1 (50:25:25), which was 0.97%. At this phase (thermophilic), all three composts, except compost 4 (100 *Sargassum*) decreased in N% values from mesophilic phase I (Figure 5.10). Furthermore, while compost 1 (50:25:25) recorded the highest total N of 1.19%, compost 3 (50:50) retained the lowest total N of 0.94% during the cooling phase of compost sampling day 30. However, the total N contents of all four composts, except compost 1 reduced slightly from the thermophilic phase (Figure 5.10).

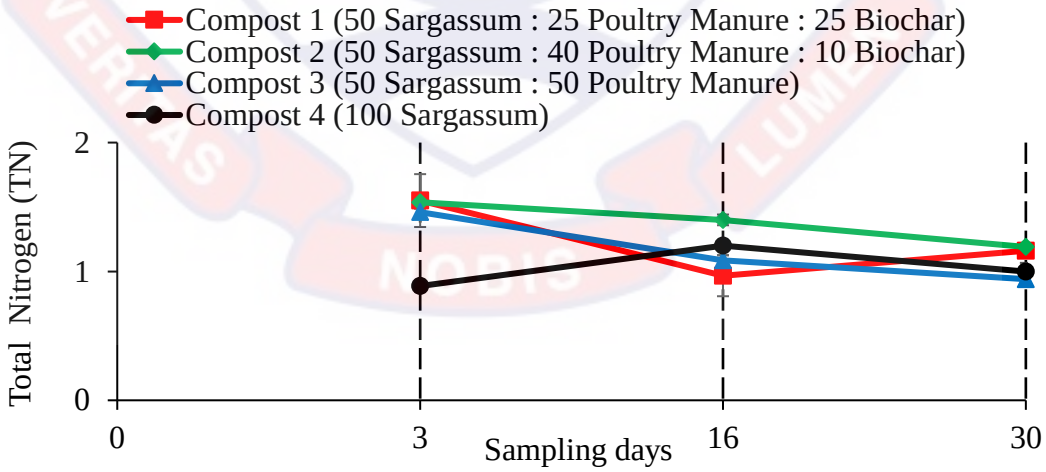


Figure 5.10: Average total nitrogen of composting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days.

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Effects of feedstock decomposition on carbon-to-nitrogen (C:N) ratio

During the mesophilic and cooling phases of the composting process, a significant (P=0.01) variation existed in the carbon-to-nitrogen ratio (C:N) (Figure 5.11). Compost 4 (100 *Sargassum*) had the highest carbon-to-nitrogen ratio (C:N) (30.3). Compost 3 (50:50) had the lowest C:N during the mesophilic phase on day 3 of the compost sampling, with a value of 14.8. The thermophilic phase, however, showed no significant difference. However, compost 1 (50:25:25) recorded the highest C:N ratio of 23.4 against 16.3 for compost 2 (50:40:10), which obtained the lowest C:N ratio during the thermophilic phase on day 16 of compost sampling. There was a reduction in value of composts 2 and 4 and an increase in values of composts 1 and 3 in terms of C:N ratios in the mesophilic phase (Figure 5.11). In addition, compost 1 (50:25:25) had the greatest carbon-to-nitrogen ratio (20.7), whereas compost 2 (50:40:10) had the lowest ratio (15.4) during the cooling phase on day 30 of the compost sampling. All the four composts saw a reduction in C: N ratio from the thermophilic phase (Figure 5.11).

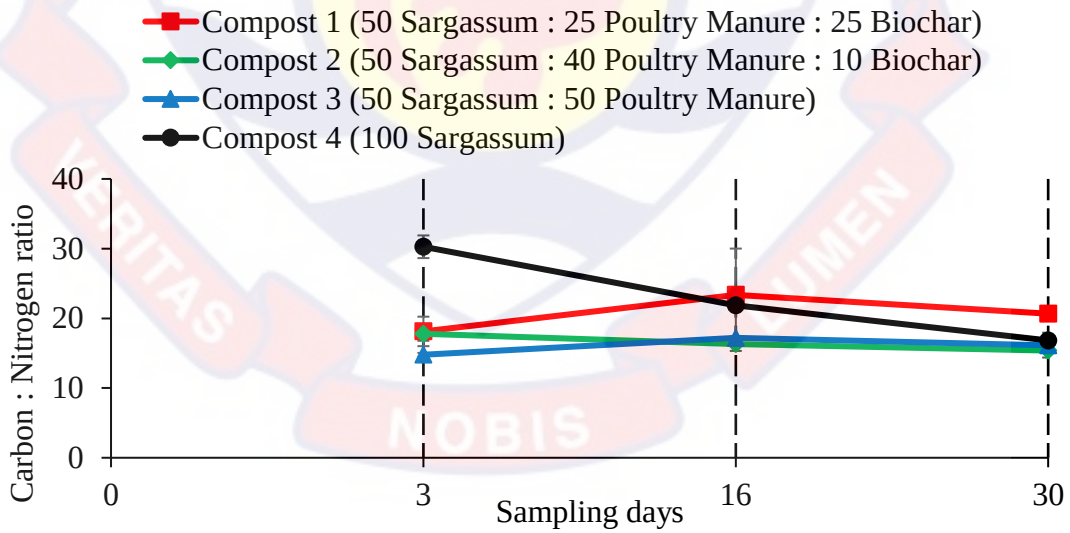


Figure 5.11: Average total nitrogen of compoting phases (mesophilic, thermophilic and cooling) showing rate of compost decomposition. Data represent the mean of four (4) replicates with error bars representing S.E.M. ANOVA established differences among sampling days.

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Chemical characteristics of matured compost

Significant (P = 0.01) differences existed among pH values (Table 5.2). The matured compost was slightly acidic in pH. Compost 1 (50:25:25) had the greatest pH of 6.9±0.0, whereas compost 4 (100 *Sargassum*) had the lowest pH of 6.5±0.1. The electrical conductivity differed significantly (P = 0.01). While the maximum EC (15.62±0.6 μScm^{-1}) was obtained in compost 4 (100 *Sargassum*), the lowest EC (8.48±0.2 μScm^{-1}) was observed in compost 1 (50:25:25). The mature compost's ash and total carbon (TC) varied significantly (P=0.01). Compost 1 had the lowest ash content (15.96±0.2%) while compost 3 (50:50) had the greatest ash content (75.00±1.8%). For total carbon (TC), the highest TC (23.05±0.3%) was attributed to compost 1 and the lowest TC (14.50±1.0%) was attributed to compost 3. In the mature compost, no significant (P > 0.05) variation existed in the amount of total N. Compost 3 (50:50) had the highest total N (0.97±0.1) measured. On the other hand, compost 1 (50:25:25) had the lowest total N (0.86±0.1). In addition, compost 3 (50:50) recorded the highest available P (1764.0±457.5μgg^{-1}), whilethe lowest available P (992.0±6.5 μgg^{-1}) was recorded in compost 4 (100 *Sargassum*). Furthermore, significant differences (P=0.01) existed in ammonium nitrogen and nitrate nitrogen in the matured compost. Ammonium nitrogen was highest (1119.0±187.6 μgg^{-1}) in compost 1 (50:25:25) and lowest (331.0±20.6 μgg^{-1}) in compost 4 (100 *Sargassum*). However, nitrate nitrogen was highest (437±41.5 $\mu gg.^{1}$) in compost 2 (50:40:10), followed by compost 3 (415.0±53.3 $\mu gg.^{1}$) and it was lowest (21.0±0.4 μgg^{-1}) in compost 4 (100 *Sargassum*). Significant difference (P = 0.01) existed in total calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) in the matured compost. Compost 2 (50:40:10) recorded the highest Ca value of 4.79±0.4% followed by compost 3 (2.81±0.6 %) and the lowest Ca value of 1.40% was recorded by compost 1 (50:25:25). However, the

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highest Mg of 1.09±0.1% was recorded by compost 1 (50:25:25) followed by 1.08±0.1 in compost 4 and the lowest Mg value of 0.33% was recorded in compost 2 (50:40:10).

Surprisingly, the highest K value of 1.11±0.2% was recorded in compost 4 (100 *Sargassum*), followed by compost 2 (0.91±0.1%) and the lowest K value of 0.14±0.1% was recorded in compost 1 (50:25:25). In addition, compost 2 (50:40:10) recorded the highest total Na of 0.84±0.1%, followed by compost 1 (0.81±0.0 %) with the lowest total Na being recorded by compost 3 (0.64±0.0) (Table 5.2). Furthermore, significant (P = 0.01) differences existed in total copper (Cu), zinc (Zn), iron (Fe) and boron (B) in the matured compost. Admittedly, Cu, Zn, Fe and B, known as heavy metals, were low in the matured compost. Total Cu, Zn and Fe were highest (0.263±0.1%, 0.066±0.0% and 0.69±0.1%, respectively) in compost 4 (100 *Sargassum*), than the rest of the composts. Compost 1 (50:25:25), recorded the highest total B of 82.0±6.3 μgg^{-1}, followed by compost 2 (70.1±2.1 μgg^{-1}), while the lowest total B (36.0±1.2 μgg^{-1}) was recorded by compost 3 (Table 5.2).

Table 5.2: Chemical characteristics of matured compost

	pH	**EC**	**Ash**	**TC**
Compost		**µS/cm**	**%**	
50 Sargassum:25 P.M:25 Biochar	6.9±0.0	8.48±0.2	59.96±0.2	23.05±0.3
50 Sargassum:40 PM:10 Biochar	6.8±0.0	10.78±0.2	63.08±1.7	21.41±1.0
50 Sargassum:50 PM	6.8±0.0	8.90±0.5	75.00±1.8	14.50±1.0
100% Sargassum	6.5±0.1	15.62±0.6	61.65±0.2	15.32±0.1
Tukey (P<0.05)	0.03**	1.12 **	3.34 **	1.98 **
CV (%)	2.3	27.2	9.6	21.1

* - Significant at 5% ; ** - Significant at 1%
EC= Electrical conductivity, TC= Total carbon

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Table 5.2 continued

	N	P	NH_4^+-N	NO_3^- -N
Compost	%	µg/g	µg/g	
50 Sarg.:25 P.M:25 Biochar	0.86±0.1	1033.0±96.6	1119.0±187.6	290.0±41.2
50 Sarg.:40 M:10 Bioc	0.93±0.1	1583.0±165.7	1003.0±169.7	437.0±41.5
50 Sargassum:50 PM	0.97±0.1	1764.0±457.5	1012.0±120.7	415.0±53.3
100% Sargassum	0.91±0.1	992.0±6.5	331.0±20.6	21.0±0.4
Tukey (P<0.05)	0.10	648.83*	367.6 **	103.6 **
CV (%)	5.8	30.5	40.1	60.5

* - Significant at 5% ; ** - Significant at 1%

N= Total Nitrogen, P=Available Phosphorus, NH_4^+-N= Ammonium Nitrogen, NO_3^--N= Nitrate Nitrogen

Table 5.2 continued

	Ca	Mg	K	Na
Compost			%	
50 Sarg:25 P.M:25 Biochar	1.40±0.1	1.09±0.1	0.14±0.1	0.81±0.0
50 Sarg:40 PM:10 Biochar	4.79±0.4	0.33±0.1	0.91±0.1	0.84±0.1
50 Sargassum:50 PM	2.81±0.6	0.93±0.2	0.72±0.1	0.64±0.0
100% Sargassum	2.91±0.1	1.08±0.1	1.11±0.2	0.75±0.1
Tukey (P<0.05)	1.38**	0.31 **	0.30 **	0.08 **
CV (%)	49.5	39.3	54.3	11.2

* - Significant at 5% ; ** - Significant at 1%

Ca= Total Calcium, Mg=Total Magnesium, K= Total Potassium, Na= Total Sodium

Table 5.2 continued

	Cu	Zn	Fe	B
Compost		%		µg/g
50 Sarg:25 P.M:25 Biocha	0.007±0.0	0.016±0.0	0.18±0.1	82.0±6.3
50 Sarg:40 PM:10 Biochar	0.007±0.0	0.024±0.0	0.04±0.0	70.1±2.1
50 Sargassum:50 PM	0.06±0.0	0.018±0.0	0.26±0.1	36.0±1.2
100% Sargassum	0.263±0.1	0.066±0.0	0.69±0.1	60.4±7.0
Tukey (P<0.05)	0.065**	0.011 **	0.18 **	12.76 **
CV (%)	165.8	69.4	88.5	29.2

* - Significant at 5%; ** - Significant at 1%

Cu= Total Copper, Zn= Total Zinc, Fe= Total Iron, B= Total Boron

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Discussion

The phases of the composting process

Mesophilic phase

The temperature rose from 30°C to between 45°C and 49°C in a few days or even hours during the mesophilic phase. This rapid increase in temperature could be due to the high respiratory activities of the microorganism (bacteria and fungi) population favoured by the greater contribution of carbon, energy, nutrients and diverse microbial population provided by the feedstocks. Temperature is the number one indicator of compost because it is closely related to organic matter decomposition, microbial growth and communities (Wei *et al.,* 2022). Soluble compounds such as sugars were decomposed at this phase, producing organic acids (FAO, 2015).

Thermophilic phase

The temperature of the parent materials was higher than 45°C during this phase. The microorganisms that grew at lower temperatures, primarily thermophilic bacteria replaced the mesophilic ones that developed at ordinary temperatures (FAO, 2015). These bacteria broke down lignin and cellulose, two complicated sources of C. The average pH increased as a result of these microbes' conversion of nitrogen into ammonia. Spores were generated by these bacteria and actinobacteria degraded hemicellulose, waxes and other C complex substances, while raising the temperature over 60°C (FAO, 2015). This stage may last long, depending on the parent material, place and climatic condition. In this study, multi-component composting, such as those with biochar, facilitated the rapid increase in temperature and prolonged the thermophilic phase as compared to single-component or two-component compost, such as 100% *Sargassum* and 50% *Sargassum* and 50% poultry manure (Wang *et al*., 2020). This implied that mixed composting could present a higher fermentation efficiency with a more appropriate process. Compost 1 (50:25:25) and compost 2 (50:40:10) were

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sharply increased in temperature, reaching 63°C and 60°C, respectively. The phase is also known as the hygienization phase. This study supports the findings by Correa *et al*. (2012) who posited a high-temperature composting process when biochar was added. The sharp temperature rise may be caused by biochar with a high-water absorption potential (Paradelo *et al.*, 2019). This study also concurs with the findings by Yang (2013) who reported that, in the composting of organic wastes, it led to a rapid increase in temperature that reached the thermophilic phase of temperature above 55°C.

Cooling phase

After the depletion of carbon and nitrogen sources in the composting material, the temperature fell to between 40°C and 45°C. In this stage, cellulose's polymer breakdown proceeded and some fungi that were visible to the unaided eye surfaced. The behaviour seen in the temperature curves had the same kinetics as conventional composting (Zibilske & Materon, 2015). At the cooling phase of the composting process, compost 1 (50:25:25) and compost 2 (50:40:10) cooled faster at a much higher temperature than compost 3 (50:50) and compost 4 (100 *Sargassum*). This study confirmed the results of numerous other researchers who discovered that adding biochar to compost enhanced its aeration (Godlewska *et al.*, 2017) and enhanced organic waste decomposition throughout the composting process (Akdeniz, 2019). In addition to promoting the degradation and accelerating the mineralization of organic matter, adding biochar to compost also increased microorganisms and their enzymes activity levels (Yin *et al.*, 2021), enabling the composting time to be shortened (Wang *et al.*, 2017) and improves the product of compost (Sanchez-Garcia *et al.*, 2015; Khan *et al.*, 2016). The alternative hypothesis is therefore accepted that sawdust biochar improves the decomposition of compost and nitrogen transformation during composting.

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Maturity phase

For humic and fulvic acids, processes such as carbonaceous compound condensation and polymerization took place throughout the months-long maturation phase at room temperature (FAO, 2015). There was no turning of the compost during this phase to allow for additional aeration and absorption of water. The compost in this study reached a steady temperature of 30^{o}C for more than three weeks, a sign of maturity.

Feedstock decomposition and pH

The pH fluctuation seen during the mesophilic, thermophilic and cooling phases perhaps was caused by the decomposition of organic matter, which resulted in the release of organic acids and CO_2 (Wang *et al*., 2021). This pH shift was caused by the many activities going on in the compost pile (Zhang & Sun, 2018). This study supports the findings of Wang *et al.* (2020) who reported that a pH range between 6.7 and 9.0 would promote microbial activity during composting. The study's findings, however, contradict those of other research projects who discovered that due to the production of organic acids, the pH at the start of composting could drop (Milon *et al*., 2022), hence the emergence of anaerobic conditions (Tautmann & Krasny, 1998). Compost 4 (100 *Sargassum*) maintained an acidic pH throughout the mesophilic, thermophilic and cooling phases. According to Ahmed *et al*. (2023), there may be a high concentration of organic acids, limited mineralization and sluggish rates of OM/organic N degradation.

Furthermore, at the mesophilic, thermophilic and cooling phases pH remained significantly higher in compost 1 (50:25:25) and compost 2 (50:40:10) than in all other compost compositions. This high pH could have been caused by the high pH in biochar as a feedstock (pH = 9.58) and the mineralization of the compost, which is consistent

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with the finding of Wang *et al.* (2017) (Figure 5.4). The null hypothesis is rejected because there was a substantial difference in pH during the mesophilic, thermophilic, and cooling phases during the composting process.

Feedstock decomposition and electrical conductivity (EC)

The total amount of soluble salt present in the compost was measured by its EC (Vicentin *et al.*, 2021). It facilitates comprehension of how compost will affect plant growth (Gondek *et al.*, 2020). Karak *et al.* (2013) stated that EC is directly linked to pH values and that EC increases as pH increases. In this study it was found that EC increased in response to increases in pH and dropped in reaction to a decrease in pH. Elevated EC levels raise the risk of salt in the soil, which can be detrimental or even lethal to plant development (Abdel-Haleem & El-Shaieny, 2015). It is true that when EC in the compost is high, it is not a good idea because salt is phytotoxic and reduces crop yield (Meng *et al.*, 2020). According to this study, adding biochar to compost raised its EC during the mesophilic and thermophilic phases with the exception of the cooling phase. This could have resulted from the compost's larger surface area and the high EC range caused by the biochar's high solubility ion, release and increased capacity to accumulate various ions (Zhang & Sun, 2017).

Feedstock decomposition and ammonium nitrogen and nitrate nitrogen

Ammonium nitrogen increased rapidly in the mesophilic phase throughout the seven days of composting, most likely as a result of organic nitrogen being converted to ammonium nitrogen by ammonification (Meng *et al.*, 2020) (Figure 5.6). During the first seven days of composting, the NO_3^--N levels stayed comparatively low. This perhaps could be due to the activity and growth of ammonia oxidizers, which were hindered by the greater temperature and lack of dissolved oxygen brought on by intense organic matter degradation and confined NO_3^--N formation from nitrification (Gao *et*

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al., 2010). Since NO_3^--N is easier for plants to absorb and use than NH_4^+-N, high-quality compost or organic fertilizer should produce enough NO_3^--N (Gross *et al.*, 2011). Zuccani & Bertoldi (1987) indicated that the upper limit for immature compost was 400 mg/kg ($\mu g g^{-1}$) of NH_4^+-N. The high NO_3^--N values during the cooling phase compared to NH_4^+-N indicated that nitrification of the organic N contained in the compost waste was high. This organic N is first released as NH_4^+-N, which is then oxidized to NO_2^--N by Nitrobacter bacteria and then to NO_3^--N by Nitrosomonas (Caurtarella, 2007). Among all the treatment combinations, compost 3 (50:50) had the highest NO_3^--N value (100 µg/g), which perhaps could be due to the feedstock's high N content in poultry manure (1.76%) (Table 5.1). The study, however, contradicts the findings of Li *et al.* (2017) and Lopez-Cano *et al.* (2016) who found that compost made with biochar had a greater NO_3^--N level than compost made without biochar. Nonetheless, the current study supports the findings of some researchers that poultry manure is known to contain significant amounts of total nitrogen among domestic animals (Ahmed *et al.*, 2007; Gao *et al.*, 2010; Amanullah *et al.*, 2010). Additionally, this study concurs with those of other researchers that carbon decomposition occurs in the thermophilic phase, while nitrogen decomposition occurs during the cooling phase (Sommer, 2001; Zhang & He, 2006; Ogunwande *et al.*, 2008).

Feedstock decomposition and C:N ratio

The ideal carbon-to-nitrogen ratio (C:N) is a crucial component of composting performance and can also serve as a sign of compost maturity (Akratos *et al.*, 2017). In order to maintain the microbial population in its most active state and speed up composting, a suitable C:N ratio is essential (Martin, 2019). The finished compost's C:N ratio of 14–18 provided a slow mineralization of nitrogen when added to the soil (Akratos *et al.*, 2017). The current study's findings support those of Nalivata (2007),

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who found that feedstock with a low C:N ratio accelerates decomposition, heat build-up, and moisture loss. However, the study differs from Walsh (2019) who discovered that a feedstock of *Sargassum* spp. before composting should have a < 20 C:N ratio. The study also supports the findings of Saeboa & Ferrini (2006), who discovered that a C:N ratio of 25:1 indicated the presence of unprocessed carbonaceous materials and resulted in a significant N drawdown during composting.

Chemical characteristics of matured compost

Since the values of the various qualities for matured compost varied with the material from which the compost was generated, there are currently no universally acknowledged standards for compost maturity specification (Bernal *et al.,* 1998; Mathus *et al.,* 1993; Warmen, 1999). However, in this study, pH levels ranged from 6.5 to 6.9, which conforms with Amlinger *et al*. (2003) who reported that nitrogen mineralization is inhibited by less than five or more than 8. Eghball (1997) reported a preferred pH level of compost to be 6.5-8.0. However, this result deviated from that of Kizza-Nkambwe *et al.* (2023) who also reported a pH level of 9.0 during compost quality assessment of peri-urban wastes in Uganda and Sullivan *et al.* (2003) who reported that the levels of pH for compost quality were 7.0-8.0. Compost 1 (50:25:25) and compost 2 (50:40:10) dosed with biochar recorded the highest pH (6.9 and 6.8, respectively), perhaps due to the high pH content in biochar feedstock, but remained in an acceptable value for microbial activity leading to compost quality (Yin *et al*., 2021). Because the activity of bacteria involved in composting is reliant on pH (Jalalipour *et al.,* 2020), deviating from the ideal range could affect the finished compost's quality. Meanwhile, since this study agrees with FAO (2015), which reported acceptable pH levels of 6.5-8.5 for matured compost, there was no doubt that the compost environment provided conditions favourable for microbial activities, leading to good compost quality

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in this research. The high EC in the study's matured compost is perhaps due to *Sargassum* spp. being the main feedstock gathered from saline beaches. Meanwhile, higher EC in the matured compost had been linked to increased phytotoxicity due to presence of Na and Cl_2 (Wilson *et al.* 2001). Furthermore, Brewer & Sullivan (2001) asserted that compost with EC higher than 5 µS/cm should be used as mulch for established plants or applied in lower concentrations.

The highest mineralization in composts 2 and 3 perhaps, was due to the 40% and 50% poultry manure incorporated into the 50% *Sargassum* as feedstock, respectively, which also had quite a high N in the feedstock (1.76%) (Table 5.1). The low content of NO_3^- in compost 1 may also be attributed to the highest temperature of 63^oC encountered in compost 3 during the composting process's thermophilic phase, which might have lost nitrogen as NH_3 gas. In addition, the lower content of NO_3^- was recorded in compost four because the *Sargassum* feedstock composted contained no poultry manure. This result disagrees with researchers' findings that the NO_3^- level of compost produced with biochar was considerably higher than those produced without biochar (Li *et al.*,2017; Vandecasteele *et al.*, 2016; Lopez-Cano *et al.*, 2016).

The ratio of NH_4^+-N:NO_3^--N remained elevated in all four composts, with compost 4 (100 *Sargassum*) exhibiting the highest ratio. Since NO_3^--N is valued by plants in their active growth periods, it was perfect to keep more of it in the compost. This study, however, contradicts previous studies (Bernal *et al.*, 1998; Xiying Hao, 2007; Pare *et al.*, 1997) that in composting, NO_3^--N ought to be higher than NH_4^+-N levels. Applying compost with C:N ratio being high to the soil, causes the immobilization of nitrogen (N) because the microorganisms consume the nitrogen from the soil to mineralize the compost. In the current study, all the compost had a relatively high C:N ratio, with the exception of compost 3 (50:50), which has the lowest ratio.

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Compost 3 also had the greatest total N value (Table 5.2). Most people agree that a compost that is stable and matured should have a C:N ratio of not more than 20 (Golneke, 1977). This study's results were at variance with those of Walsh (2019) who found that mature *Sargassum* compost had a carbon-to-nitrogen ratio of less than 20.

The compost has relatively low total N levels, 0.86% to 0.97%, which is consistent with those of Sullivan *et al.* (2003), who reported a range of total N values between 0.7% and 1.5%. Following active composting, the microorganisms liberated all of the nitrogen and sequester it within the compost matrix, where it is subsequently released as compost during post-compost mineralization (Maynard, 1994).

Because the created compost has high levels of exchangeable P, total cations (Ca K, Mg & Na) and heavy metals (Zn, Cu, Fe and B), it may be a viable choice for releasing plant nutrients for plant uptake. Furthermore, the original composition of the poultry manure increased the functional exchange groups, which may have contributed to the increases in TC contents and the high CEC value (Sartor *et al*., 2012). The alternative hypothesis is accepted since there was significant difference in the mature compost's chemical properties.

Conclusion

There were sufficient nutrients in the biochar feedstock, poultry manure and *Sargassum* spp. for composting. The mesophilic, thermophilic and cooling phases of the composting process were all able to proceed with minimal to ideal temperatures due to the combination of the feedstock and the Cornell composting formula. This allowed microorganisms to break down organic matter more easily, producing mature compost of high quality. During composting, sawdust biochar enhanced the breakdown of organic materials and nitrogen transformation.

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CHAPTER SIX

MINERALIZATION OF INCUBATED SARGASSUM SPP. COMPOST IN COASTAL SAVANNAH HAPLIC ACRISOL SOIL

Introduction

Organic fertilizers are essential in sustainable agriculture in order to increase crop productivity, soil organic matter, soil physical and chemical properties and a steady supply of nutrients (Khan *et al.*, 2007; Hati *et al.*, 2007; Liu *et al.*, 2009). Factors facilitating the biochemical process of mineralization of nutrients from soil organic matter (SOM) include environmental conditions, soil properties, soil microbial communities, agricultural practices, soil moisture content, soil temperature and agricultural practices (Chang *et al.*, 2014; Rui *et al*., 2011; Pinto *et al*., 2020; Xiao *et al*., 2013).

Most N plants absorb inorganic N pools, primarily from NH_4^+ and NO_3^-. Therefore, a major element regulating the N supply for crops is the rate at which organic N decomposes and mineralizes to inorganic N (Zhang *et al*., 2015). Large amounts of macronutrients are released by soil organic matter through mineralization, a gradual process that encourages greater plant uptake and less loss of nutrients (Rahman *et al*., 2013). Manojlovic *et al*. (2010) reported that because nutrients are released from manures gradually and steadily, plants can utilize them for a longer time without suffering a significant loss. Additionally, the physical, chemical and biological properties of soil microbes as well as the chemical make-up of organic matter such as N content, the C:N ratio and the amounts of cellulose and hemicelluloses, lignin and polyphenols affect how much nitrogen is released to crops (Calderón *et al.*, 2005; Manojlovic *et al.*, 2010; Mohanty *et al.*, 2011). Organic additions with high nitrogen content and low carbon-to-nitrogen ratio mineralize adequate nitrogen to sustain plant

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growth (Cordovil *et al.*, 2005; Seneviratne, 2000). However, organic amendments that have lower N contents and greater C:N ratios have the ability to immobilize N (Manojlovic *et al.*, 2010). Two main goals are driving research into the N mineralization dynamics of agricultural amendments: first, to reduce nitrogen losses to the environment and avoid over-fertilizer application and secondly to optimize crop yields through management of residues in low-input agriculture that depends on nutrient recycling (Bruun *et al*., 2006).

The plants might eventually be able to get significant amounts of the nutrients that are bonded to the residue. Thus, to enhance and optimize N supply to the crop and reduce N losses, net N mineralization should coincide with plant or crop development (Abbasi *et al.*, 2015). The study, therefore, assessed nitrogen, phosphorus and potassium mineralization through incubation in coastal savannah soil that has been amended with four *Sargassum* spp. compost.

Objectives

1. To determine nitrogen, phosphorus and potassium mineralization dynamics of soil amended with *Sargassum* compost of varying composition.

2. To evaluate *Sargassum* compost of varying composition on pH, EC, total C and N and on the CEC of the soil.

Hypothesis

Ho: The mineralization of four composts of *Sargassum* species are the same.

H_1: The mineralization of four composts of *Sargassum* spp. are not the same.

Materials and methods

Field soil sampling

Within the 1-acre research area, samples were obtained with a soil auger at 12 different locations, with depths ranging from 0 to 20 cm. Before transporting to the soil

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science laboratory of the University of Cape Coast for chemical analysis, the soils underwent several processes including composite drying, air-drying, grinding with a mortar and pestle to extract fine fractions, sieving through a < 2 mm sieve to extract fine fractions and packing the mixture into labelled polythene bags. The sieved soil samples were then subjected to an analysis of the physico-chemical parameters of the soil, which included pH, particle size distribution, bulk density, total organic carbon, total nitrogen, accessible phosphorus, exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}), ECEC and exchangeable acidity (H^{+}+Al^{3+}). Fresh soil samples were used to calculate the moisture content and bulk density. In the past, maize was planted in the land.

Laboratory analysis of soil samples

Soil bulk density determination

Using core samplers, soil samples were taken from each replicate's two primary plots. The fresh weight of the core samples was ascertained in the laboratory subsequent to their collection. The core samplers and their contents were weighed and then baked for 48 hours at 105ºC. After being taken out of the oven, the samplers were allowed to cool for half an hour in a desiccator. To find the weight of the dry soil samples, they were then weighed. The soil bulk density was calculated using the formula below:

$$\text{Bulk density (gcm-}^{3}\text{)} = \frac{weight\ of\ oven\ dry\ soil}{volume\ of\ bulk\ soil} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [6.1]$$

Soil moisture content determination

Ten (10) g of fresh soil samples each were put into beakers that had been cleaned. The soil samples were dried at 105ºC for 48 hours in an oven. The samples were removed from the oven and allowed to cool for half an hour in a desiccator. The soil samples' dry weights were computed following chilling. The following formula was used to determine the percentage moisture content of the soil samples:

$$\text{Moisture content (\%)} = \frac{weight\ of\ fresh\ soil - weight\ of\ oven\ dry\ soil(g)}{weight\ of\ oven\ dry\ soil(g)} \text{ x } 100 \quad \ldots\ldots \quad [6.2]$$

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pH of soil determination

Ten (10) g of air-dried, 2 mm sieved soil samples were weighed in duplicate into 50 mL centrifuge tubes; 25 mL of distilled water were also added; the centrifuge tubes were covered securely and placed on a motorized shaker for fifteen minutes to equally mix the soil samples. The tubes were then removed and the pH of the soil samples was determined using the pH meter.

Particle size distribution

Particle size distribution for soil textural class was carried out according to Rowel (1994) using the pipette method. Ten (10) g of two (2) mm sieved, air-dried soil samples were weighed into separate beakers, and then 50 mL of distilled water were added. 10mL of hydrogen peroxide (H_2O_2) were then added to the resultant solution in order to oxidize the soil material. The soil samples that were treated with hydrogen peroxide were then quantitatively placed into 500 mL plastic bottles and 10 mL of sodium hexametaphosphate $(NaPO_3)_6$ were added to each soil solution. After leaving the bottles holding the soil solutions on a mechanical shaker for the entire night, the samples were removed and weighed into 500 mL measuring cylinders. Each sample solution was then filled up to the 500 mL mark using distilled water.

Separation of silt and clay fractions

A calibrated retort stand fitted with a 25 mL pipette was used to calculate the silt and clay fraction. After the pipette tip briefly touched the surface of the soil solution in the measuring cylinder, the value (d/cm) was obtained. To ensure that all of the dirt was out of the bottom, the cylinder was shaken very hard for five minutes. After 40 seconds, a pipette was dipped (d + 10 cm) deep into the soil solution to transfer 25 mL of the soil solution into a beaker. On the remaining soil solutions in the measuring

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cylinders, the procedure was followed. Five hours were spent letting the soil solutions in the measuring cylinders stand before the clay fraction was calculated.

Separation of only clay fraction

The soil particles that remained suspended after five hours were known as the clay fractions. The pipette was lowered progressively until the tip came into contact with the surface of the soil solution. In accordance with the determination of clay and silt, the value was observed and recorded as d in cm. Pipetting of the soil solution into different beakers was done in increments of 25mL.

Separation of sand fraction

After eliminating the clay fraction, the residual material consisted of sand, tiny silt and clay fractions that gathered at the bottom of the measurement cylinder. The liquid that had been left behind after gently draining was then quantitatively poured into a beaker. The material was mixed with water and allowed to settle for thirty seconds. After 30 seconds, the water was carefully decanted, and the sediment-containing supernatant was maintained in the beaker. This procedure was continued until the supernatant was clear.

Soil total nitrogen, & cation exchange capacity determination

The procedures for determining soil's total organic carbon, nitrogen and cation exchange capacity have been described in Chapter 5.

Soil available phosphorus determination

The amount of accessible phosphorus in the soil samples was ascertained using the Bray No. 1 method, which is detailed by Page *et al.* (1982). Ten millilitres of the extraction solution were added to a 50 mL centrifuge tube containing one (1) gram of the air-dried soil sample. The tubes were agitated on a mechanical shaker for five minutes to drain the soil solution and then, they were quantitatively transferred into a

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50 mL conical flask lined with Whatman filter paper. 1 mL of the filtrate was pipetted into a 25 mL round-bottom test tube, followed by the addition of 4 mL of the colour-forming reagent (B). The resultant solution was then topped off with distilled water to the 25 mL mark to develop the colour. A spectrophotometer (CE 1000 series) was used to measure the absorbance of the solution at 882 nm. From 5 g P mL^{-1} of the stock solution, standard working solutions of P (0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 g mL^{-1}) were made. A spectrophotometer was used to measure the absorbances of the standard solutions at 882 nm after they had been let to develop in colour for 15 minutes. For the standard solution, absorbance vs. concentration was graphed to construct a calibration curve. The concentration of P in the soil sample aliquot was calculated using the calibration curve from the following formula:

$$\mu g\ P\ g^{-1}\ soil = \frac{C\ X\ Dilution\ factor}{weight\ of\ soil} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [6.3]$$

Where: C =Concentration of P obtained from the calibration curve ($\mu g\ mL^{-1}$).

Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) determination

The Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} were extracted by weighing 5 g of the sieved soil sample into 50 mL centrifuge tubes (Rowel, 1994). After adding 20 mL of ammonium acetate solution and shaking it for an hour, it was allowed to stand overnight. 100 mL conical flasks lined with Whatman filter paper were filled with the suspension. The dirt collected on the filter paper was successively leached with 20 mL of the NH_4OAc solution until 100 mL of the filtrate were obtained. Calculations were performed on the collected filtrate to determine the concentrations of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}. EDTA titrimetry was used to determine the levels of calcium and magnesium, whilst a flame photometer was used to assess Na and K.

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Determination of exchangeable acidity (H^+ Al^{3+})

The suggested standard laboratory technique was used to determine the exchangeable acidity (Rowel, 1994). 50 mL centrifuge tubes were filled with 10 grams of 2 mm sieved soil and 20 mL of a 1 M KCl solution. For one hour, the soil samples were shaken using a mechanical apparatus. One by one, 10 mL portions of the KCl solution were added to each soil sample. To raise the filtrate's volume to 100 mL, part of the KCl solution was added. A 50 ml aliquot and five drops of phenolphthalein indicator were pipetted into a 100 mL conical flask. The resultant solution was titrated from colourless to pink using a 0.01M NaOH solution. Measured are the interchangeable Al^{3+} + H^+.

$$\text{Cmol}_c\ H^+ \text{ and } Al^{3+}\text{kg}^{-1}\text{ soil} = {0.2\ x(S-B)X10}\Big/{Weight\ of\ soil(g)} \quad \text{[6.4]}$$

where:

S = Sample titre value

B = Blank titre value

Determination of calcium, magnesium and soil electrical conductivity

The determination of calcium, magnesium, and soil electrical conductivity was described in Chapter 5.

Total organic carbon determination

Walkley-Black method was used to determine the total organic carbon content of the soil. Ten (10) mL of 1 N potassium dichromate and twenty (20) mL of concentrated (98%) sulphuric acid (H_2SO_4) were added to an Erlenmeyer flask that held 0.5 g of soil. The flask was spun, left to stand for thirty minutes and then 200 mL of distilled water were added, mixed and allowed to cool. After 10 mL of 85% orthophosphoric acid and 1 mL of an indicator solution (barium diphenylamine sulphate) were added and the remaining dichromate in solution after the oxidation of

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the oxidizable organic material in the soil sample was titrated against 0.5 N ferrous sulphate solution and titrated to a green end point. A blank was employed as a check, and the identical process was followed, but no soil sample was used. The carbon content was determined below:

$$\% \text{ SOC } = \frac{[10-XN] \times 0.3 \times 1.333}{\text{sample weight}} \ldots\ldots \quad [6.5]$$

X = titrated volume of ammonium ferrous sulphate solution

N = Normality of ferrous ammonium sulphate (10/volume of ammonium sulphate titrated with the blank.)

W = weight of soil samples taken, 0.3 = milliequivalent of carbon

1.33 = correction factor Walkley and Black assume an average 77% recovery of organic carbon by this method.

Compost mineralization experiment to release nitrogen, phosphorus and potassium

The incubation experiment to assess nitrogen, phosphorus and potassium mineralization spanned between 8th February and 7th April, 2023. The Haplic Acrisol soil from one of the fields at the Alexander G. Carson Technology Centre was sampled for the incubation experiment. Soil samples and compost were ground and filtered through a 2 mm sieve to exclude any undesired extraneous material. They were then allowed to air-dry and spread out on brown paper for a few days. Additionally, moist soil from the field was gently filtered using a 4.75 mm sieve to remove stones, surface litter and root debris.

After sieving, 1 kg of soil samples was weighed and put into 12 cm-tall plastic pots with 10 cm in the top and 7 cm in the bottom for internal diameters. The bases of the pots were perforated with three 0.5 cm diameter holes to let excess water to drain, but the holes were filled with filter paper to keep soil from being lost. Subsequently, the

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soil was compressed to get a bulk density of 1.3 g cm^{-3}, which corresponded to the density recorded on the field. The quantities of compost applied per pot to give the equivalent rates of compost/ha were no compost (T1 = control), Inorganic fertilizer (T2) made up of NPK (23:10:5), Urea (46% N), Muriate of Potash (60%K_2O) & Tripple superphosphate (46%P_2O_5), compost 1 (T3 = 34,918.6kg/ha = 27.02 g for 1kg soil), compost 2 (T4 = 32,290.4 kg/ha = 25.9 g for 1kg soil), compost 3 (T5 =30,958.80 kg/ha = 33.15 g for 1kg soil) and compost 4 (T6 = 33,000.03 kg/ha=25.3g for 1kg soil).

The pots were filled with the treatments, and after labelling the pots, they were put in the cupboard of the Soil Science Laboratory, UCC arranged in a Randomized Complete Design (RCD) with four replications. Before the commencement of the incubation experiment, each sample was kept in a dry, cool environment. In order to assess nitrogen, phosphorus and potassium mineralization, the soil was incubated with the produced compost at 27–30 °C, 90%–95% humidity, and dark aerobic conditions for 60 days in a laboratory setting. During the incubation period, the weight loss of every amended pot was recorded every day. To maintain a 55% water-filled pore space (WFPS) in all soils, distilled water was added to each pot based on the bulk density and gravimetric moisture content (Masunga *et al.*, 2016).

On days 0, 3, 14, 21, 28, 42 and 60, fresh media samples were taken for chemical analysis in the laboratory. Six hours after starting the microbiological process in the treatment pots, day 0 was sampled. In the Soil Science Laboratory at UCC, the following parameters such as total N, NH_4^+-N, NO_3^--N, EC, pH, P, K, CEC and total carbon were analyzed.

Inorganic fertilizer application

For 1kg soil holding capacity pots, for the incubation experiment NPK (23:10:5), Muriate of potash (K_2O 60%), Triple superphosphate (46%) and Urea (46%)

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were applied once at the rate of 0.0765 NPK per/pot, 0.0256 K_2O per pot, 0.0335 P_2O_5 per pot and 0.0452 N per pot respectively.

Statistical analysis

To ascertain the significance of the data, general analysis of variance (ANOVA) was carried out using GenStat Twelfth Edition, Procedure Library Release PL20.I, 2009 (VSN International Limited, Rothamsted Experimental Station, Hemel Hempstead, UK). The data were graphically represented using Microsoft Excel, and the means were separated using Fisher's Protected Least Significant Difference test at 5% probability and Tukey's Honestly Significant Difference (HSD).

$$y_{ij} = \mu + c_i + r_j + \varepsilon_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad [6.6]$$

Where y_{ij} = observation from the i^{th} compost and j^{th} replication, μ = overall mean, c_i = effect of the i^{th} compost, r_j = effect of the j^{th} replication, and ε_{ij} = the experimental error.

Results

Physico-chemical properties of soil

The soil had a pH of 6.49±0.04 which is slightly acidic according to an analysis of soil samples taken before the incubation and the pot experiment (Table 6.1). Tables 6.1 and 6.2 provide an overview of the soil's physico-chemical characteristics.

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Table 6.1: Chemical properties of soil

Parameter	Unit	Mean value
pH	-	6.49±0.04
Organic carbon	%	0.57±0.01
Total nitrogen	%	0.05±0.01
Ammonium nitrogen (NH_4^+-N)	µg/g	51.33±0.77
Nitrate nitrogen (NO_3^--N)	µg/g	6.83±0.09
Exchangeable P	µg/g	11.07±0.02
Exchangeable cations		
K^+	cmol/kg	0.24±0.02
Na^+	cmol/kg	0.07±0.01
Ca^{2+}	cmol/kg	3.40±0.08
Mg^{2+}	cmol/kg	1.25±0.02
Exchangeable acidity (Al^{3+}+H^-)	cmol/kg	0.21±0.01
ECEC	cmol/kg	5.19±0.03
EC	µS/cm	80.75±0.33
CEC	cmol/kg	2.59±0.02

K^+=Potassium ion, Na^+=Sodium ion, Ca^{2+}=Calcium ion, Mg^{2+}=Magnesium ion, CEC= Cation exchange capacity, ECEC=Effective cation exchange capacity, EC= Electrical conductivity

Table 6.2: Physical properties of soil

Parameter	Value	Texture
Particle size distribution		
Sand (%)	79.02±0.80	
Silt (%)	13.3 ±0.12	Sandy loam
Clay (%)	7.68±0.04	
Bulk density (gcm^{-3})	1.30±0.08	

Soil amendments mineralization and pH dynamics after incubation

Significant (P=0.01) differences existed in soil amendments mineralization on the pH of the incubated soil on days 3-14 and days 28-60 (Figure 6.1). The pH increased from day 0 and peaked at day 7 (7.8) for all treatments except compost 4 (100 *Sargassum*) which peaked at days 21 and 28 (7.4). Day 42 saw a slight increase in pH (7.1) before ending with a pH of 7.0 on day 60. However, in soil without compost, the pH decreased from day 14 to day 42 (6.8) and then increased slightly on day 60 (6.9). Similar observations were made in compost 3 (50:50) where pH decreased from day 14 up to day 42 (7.2) and then increased slightly again in day 60 (7.3). On day 0, pH of

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compost 1 and compost 2 were similar (7.2). Similar observation was made in compost 3 and compost 4 having similar pH (7.3). On day 3, while pH of compost 1 and compost 3 were similar (7.6), they differ significantly from compost 2 in terms of pH (7.7). On day 7, the pH of soil amended with inorganic fertilizer and compost 1 were similar in pH (7.8) as well as compost 2 and 3 (7.9). However, on day 14, soil amended with inorganic fertilizer, composts 1, 2 and 3 had similar pH (7.6).

Treatments T4 (50:40:10) and T5 (50:50) resulted in significantly higher pH during mineralization than all other treatments, although these treatments were not significantly different in their pH effects. The order of increasing effects of amendments on pH on day 7 for example, was T6<T1<T2=T3<T4=T5 (Figure 6.1). The results further indicated that as sole *Sargassum* compost was halved and replaced by poultry manure, there was a sharp rise in soil pH, which was maintained after 20% replacement with biochar. However, the stepwise reduction of poultry manure with subsequent replacement with biochar dopped, thus, a rise effect (Figure 6.1).

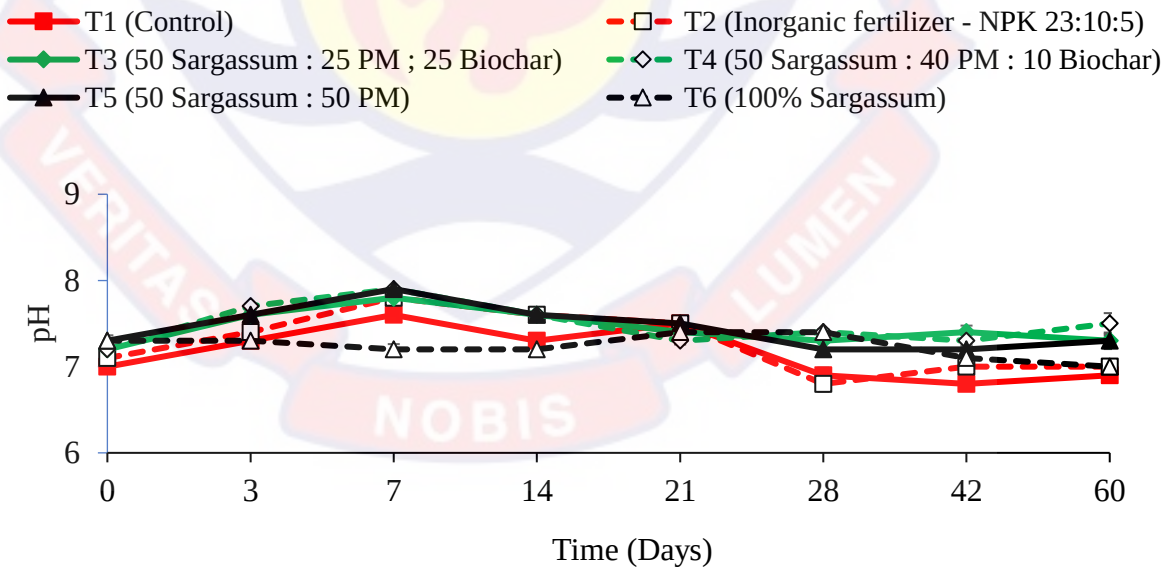


Figure 6.1: Influence of soil amendments mineralization on soil pH dynamics after incubation. Data represents the mean of four (4) replicates with error bars representing standard error of the mean (S.E.M).

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Soil amendments mineralization and electrical conductivity (EC) dynamics

Except for day 0, there was a significant (P = 0.01) influence of compost mineralization on the EC of the incubated soil from day 3 to 60 (Figure 6.2). Except for compost 4 (100 *Sargassum*) and soil amended with inorganic fertilizer, in which EC values were high on day 0, the rest of the treatments recorded high values before these values decreased as the day progressed. Electrical conductivity rose in compost 4 (100 *Sargassum*), and the value reached its peak in day 7 (149.2 μScm^{-1}) (Figure 6.2). Afterwards, the EC values started to decrease until day 60. For the soil amended with inorganic fertilizer, the highest EC value was recorded on day 28 (48μScm^{-1}) before values started reducing up to day 60 (33.8 μScm^{-1}). Despite all the decreasing values in all the treatments on day 60, compost 2 (50:40:10) and compost 3 (50:50 saw a slight increase in value that was 31.1 μScm^{-1} and 34.6 μScm^{-1}, respectively, on day 60.

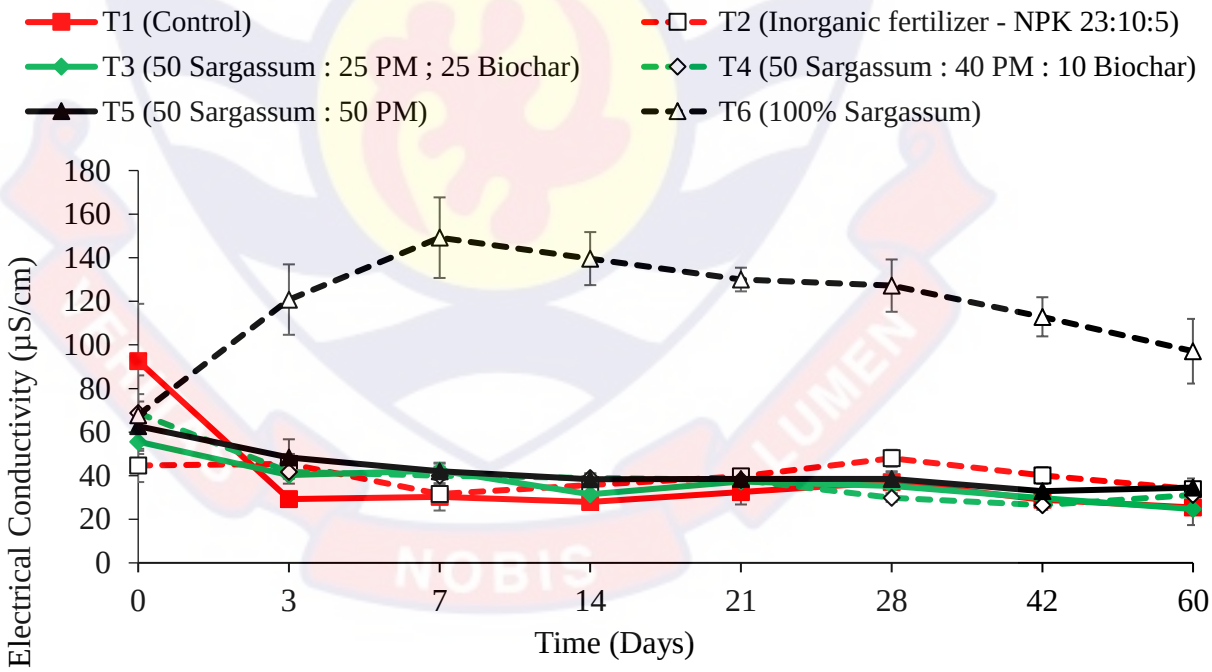


Figure 6.2: Influence of soil amendments mineralization on soil electrical conductivity (EC) dynamics after incubation. Data represents mean of four (4) replicates with error bars representing standard error of the mean (S.E.M).

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Soil amendments mineralization and ammonium nitrogen (NH_4^+-N) dynamics

Except for day 60, significant (P = 0.01) differences existed in the mineralization of soil amendments into ammonium nitrogen of the incubated soil from day 0 to day 42 after the incubation (Figure 6.3). There is a general increase in NH_4^+-N from day 0 and its peak values were reached at day 7 for all the treatments (soil amended with no compost = 63.3µg/g, soil amended with inorganic fertilizer = 62 μgg^{-1}, compost 1 (50:25:25) =57.4 μgg^{-1}, compost 2(50:40:10) = 52.4 μgg^{-1}, and compost 3 (50:50) =49.7 μgg^{-1}, respectively), except compost 4(100 *Sargassum*) which had its highest NH_4^+-N value (93.1μgg^{-1}) in day 3 of the incubation (Figure 6.3). From day 7, the NH_4^+-N values for all the treatments decreased until day 14. All treatments showed an overall decrease in NH_4^+-N levels on day 14. However, there was an increase in NH_4^+-N values for all treatments on day 21, except compost 3 (50:50), which had a reduction in NH_4^+-N value (47.8 μgg^{-1}). Again, on day 28, while there was an increase in NH_4^+-N values for soil amended without compost, compost 2 (50:40:10) and compost 4 (100 *Sargassum*) (51.0 μgg^{-1}, 41.0 μgg^{-1} and 93.0 µg/g, respectively), soil amended with inorganic fertilizer, compost 1 (50:25:25) and compost 3 (50:50) saw a reduction in NH_4^+-N values (56.7 μgg^{-1}, 41.0 μgg^{-1} and 39.1μgg^{-1}) respectively. On day 42 of the incubation, all the treatments witnessed a reduction in NH_4^+-N values, except on day 60. In contrast, half the treatment saw a reduction in NH_4^+-N values again, that is (soil amended with no compost (42.0 μgg^{-1}), compost 1 (50:25:25) (33.1 μgg^{-1}) and compost 4 (100 *Sargassum*) (67.4 μgg^{-1}) respectively while soil amended with inorganic fertilizer, compost 2 (50: 40:10) and compost 3 (50:50) witnessed an increased in NH_4^+-N values (47.8 μgg^{-1}, 43.0 µg and 53.5 μgg^{-1} respectively) (Figure 6.3).

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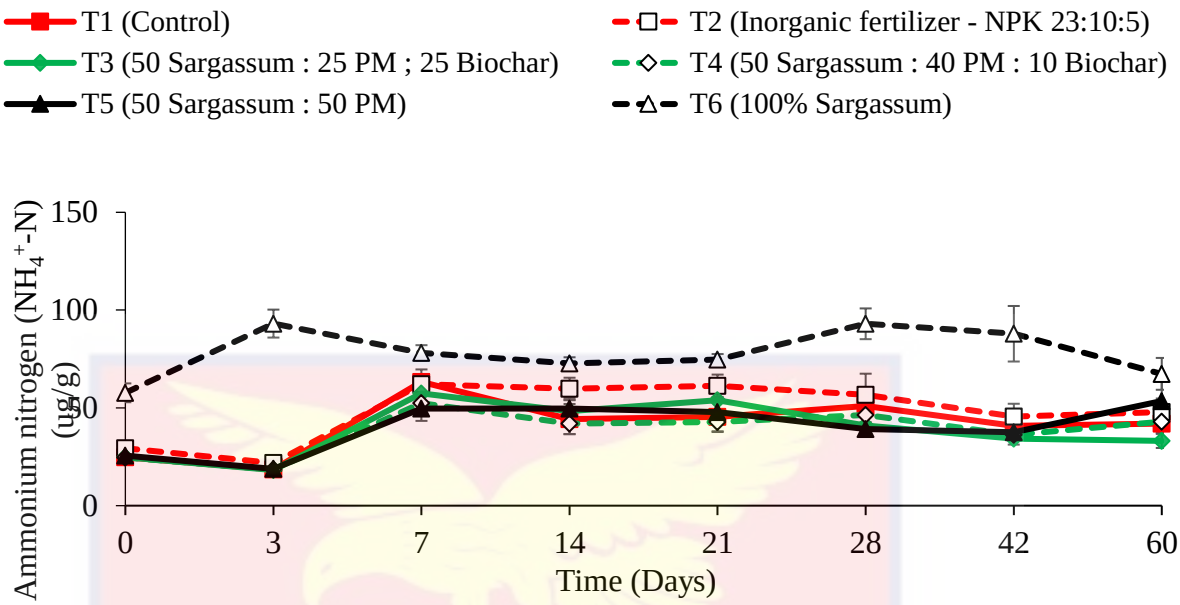


Figure 6.3: Influence of soil amendments mineralization on soil ammonium nitrogen (NH_4^+-N) dynamics after incubation. Data represents mean of four (4) replicates with error bars representing standard error of the mean (S.E.M).

Soil amendments mineralization and nitrate nitrogen (NO_3^--N) dynamics

Significant (P = 0.01) difference existed in the effects of soil amendments mineralization on NO_3^--N of the incubated soil on days 7, 14, 21 and 60 after incubation (Figure 6.4). The remaining days, 0, 3 and 42, were insignificant at 5 %. Nitrate nitrogen attained its peak values on day 7 in soil amended with no compost (4.16 $\mu g g^{-1}$), compost 2 (50:40:10) (3.66 $\mu g g^{-1}$) and compost 3 (50:50) (4.04 $\mu g g^{-1}$). However, NO_3^--N values were highest on day 14 for soil amended with inorganic fertilizer (6.16 $\mu g g^{-1}$) and compost 1 (50:25:25) (2.62 $\mu g g^{-1}$). Furthermore, compost 4 (100 *Sargassum*) attained its peak value (9.08 $\mu g g^{-1}$) on day 60 after the incubation. Meanwhile, compost 4(100 *Sargassum*) started with a higher NO_3^--N value on day 0 (1.55 $\mu g g^{-1}$), which is a slight deviation from the rest of the treatment that started from low NO_3^--N values on day 0 after the incubation (Figure 6.4).

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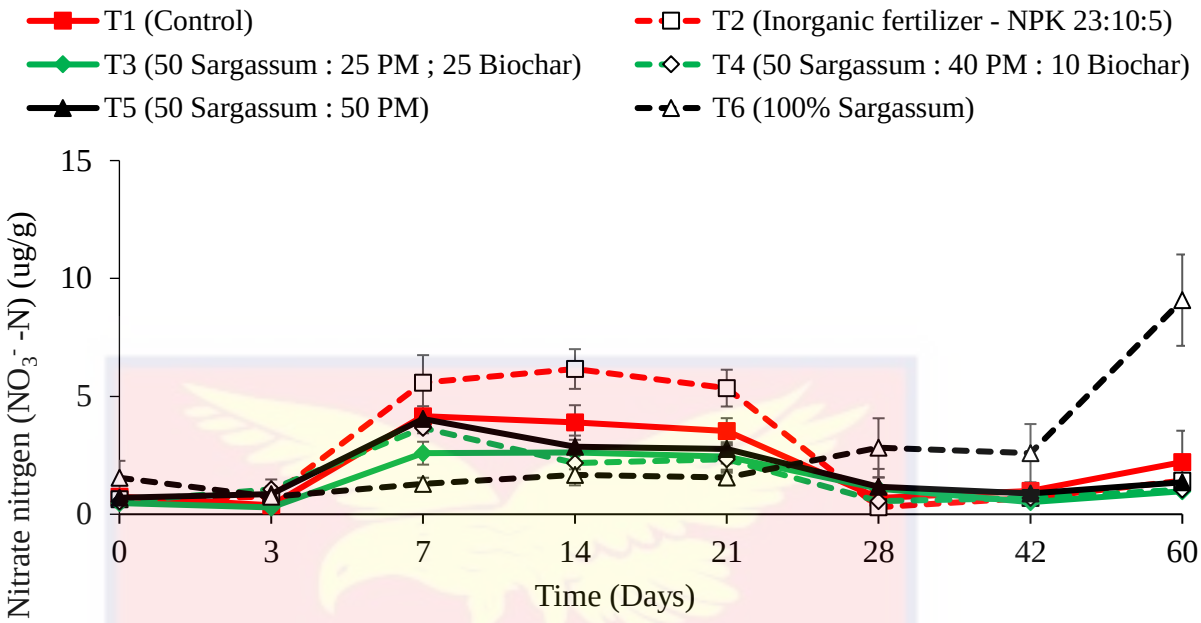


Figure 6.4: Influence of soil amendments mineralization on soil nitrate nitrogen (NO_3^--N) dynamics after incubation. Data represents the mean of four (4) replicates with error bars representing standard error of the mean (S.E.M).

Soil amendments mineralization and carbon to nitrogen ratio (C:N) dynamics

On day 0 and day 3 of incubation, significant (P=0.01) differences existed in the effects of mineralization of soil amendments on the C:N ratio of the incubated soil (Figure 6.5). On day 60 following the incubation, there was also a significant difference ($P < 0.05$) in the compost mineralization on the C:N ratio (Figure 6.5). C:N ratio increases in the soil treated without compost from day 0–7 and peaks on day 14 (26.7). Day 21 to day 42 saw a drop in this figure (26.7), which increased again on day 60 (25.4). In the soil that has been supplemented with inorganic fertilizer, the C:N ratio increased from day 0 to day 3 when it reached its maximum value of 60.3. The C:N levels varied throughout the course of the days, peaking at day 60 (27.2). In compost 1 (50:25:25), there was an increase in the C:N ratio values from day 7 to day 21, where it peaked (30.0) before it decreased on day 28 (25.4) and it increased again from day 42 to day 60 (28.0). For compost 2 (50:40:10), an initial C:N ratio decreased from day 0 to

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day 3 (21.2). After that, from day 7 to day 21 (18.0), the C:N ratio levels dropped. Day 28 to day 42 (25.7) saw an increase in these C:N ratio values, which then decreased on day 60 (25.4). For compost 3, on the other hand, the C:N ratio increased from day 0 to day 3 (47.5), which was also the peak value, and subsequently it fell from day 7 to day 14 (25.3). However, the C:N ratio increased and decreased from day 21 (26.0) to day 60 (25.4). In compost 4 (100 *Sargassum*), the C:N ratio values decreased from day 0 to day 3 (23.9). These C:N ratios increase from day 7 (29.8) to day 21 as the peak value (103.0). From day 28, the C:N ratio increased to day 60 (36.4) (Figure 6.5).

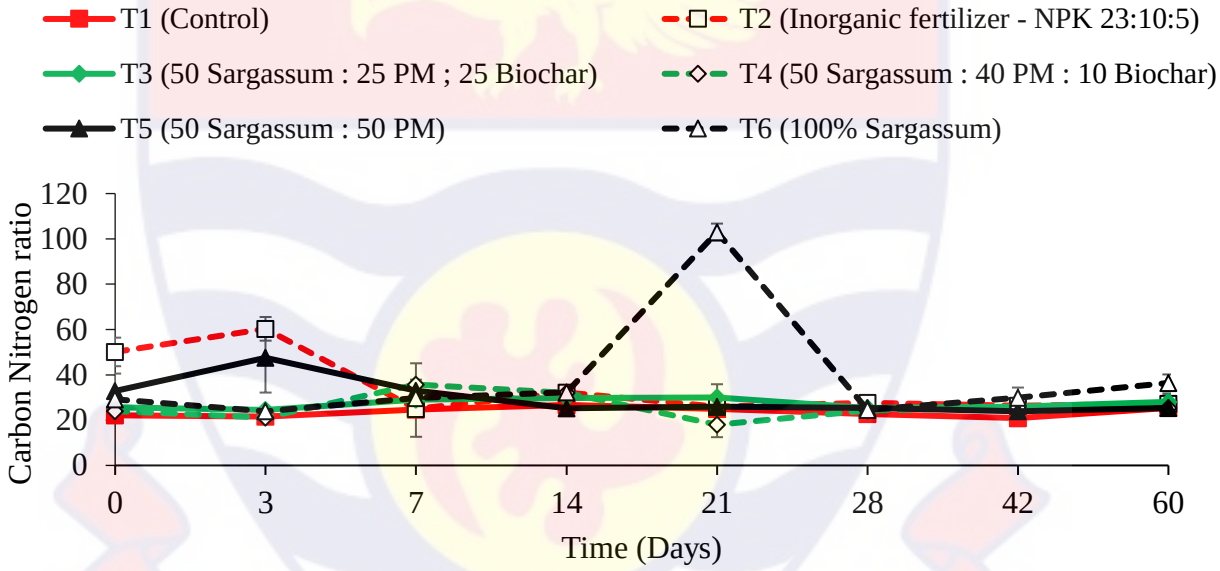


Figure 6.5: Influence of soil amendments mineralization on soil carbon- to-nitrogen ratio (C:N) dynamics after incubation. Data represents the mean of four (4) replicates with error bars representing standard error of the mean (S.E.M.)

Soil amendments mineralization and available phosphorus (P) dynamics

Significant (P = 0.01) difference existed in the effects of soil amendments mineralization on available phosphorus of the incubated soil on day 28 after the incubation (Figure 6.6). For the soil amended with no compost, mineralization of available phosphorus decreases in value from day 0 to day 14 (0.35 $cmolkg^{-1}$) and increases in available phosphorus value from day 21 to day 60 (4.20 $cmolkg^{-1}$). For soil amended with inorganic fertilizer, there was a decrease in P value from day 0 (9.09

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cmolkg^{-1}) to day 21 (4.48 cmolkg^{-1}). The highest value of available P was observed on day 60 (16.40 cmolkg^{-1}). For soil amended with compost 1 (50:25;25), phosphorus mineralization surprisingly obtained its highest P value on day 0 (7.67 cmolkg^{-1}). The P values, again, decreased from day 0 to day 28 (3.63 cmolkg^{-1}), and later increased from day 42 to day 60 (6.40 cmolkg^{-1}) (Figure 6.6). In compost 2 (50:40:10), P values decreased from day 0 (9.08 cmolkg^{-1}) to day 3 (8.06 cmolkg^{-1}) before peaking on day 7 (20.70 cmolkg^{-1}). The P value decreased on day 14 (4.20 cmolkg^{-1}), increased and decreased in value and finally increased on day 60 (7.00 cmolkg^{-1}) (Figure 6.6). For soil amended with compost 3 (50:50), available P values, again, decreased from day 0 (12.56 cmolkg^{-1}) through to day 28 (3.34 cmolkg^{-1}), and the P values increased from day 42 (4.15 cmolkg^{-1}) to day 60 (5.20 cmolkg^{-1}). However, in compost 4 (100 *Sargassum*), there was an increase in P value from day 0 (5.96 cmolkg^{-1}) to day 7 (11.0 cmolkg^{-1}) and decreased from day 14 (6.68 cmolkg^{-1}) to day 21 (6.16 cmolkg^{-1}). On day 28, the P value, increased, again, (10.82 cmolkg^{-1}) before finally decreasing to 6.70 cmolkg^{-1} on day 60 (Figure 6.6).

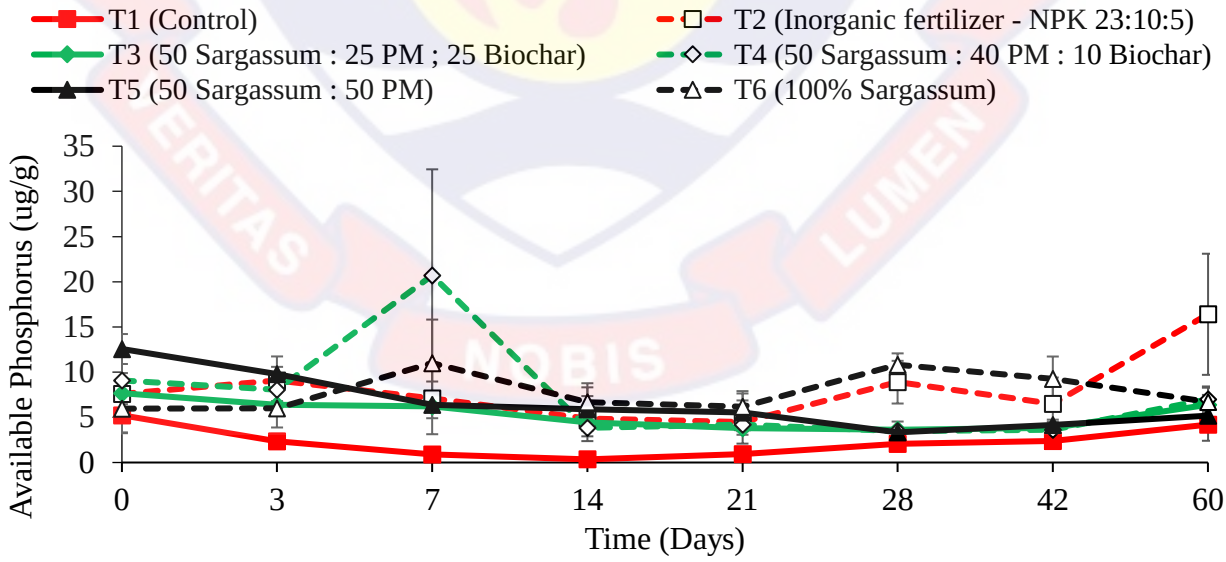


Figure 6.6: Influence of soil amendments mineralization on soil available phosphorus (P) dynamics after incubation. Data represents the mean of four (4) replicates with error bars representing standard error of the mean (S.E.M.)

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Soil amendments mineralization and exchangeable Potassium (K) dynamics

Significant (P = 0.01) differences existed in the mineralization of soil amendments on exchangeable potassium of the incubated soil on days 3, 14, 28 and 60 after the incubation (Figure 6.7). No significant differences existed for the rest of the days (Figure 6.7). The soil without compost amendment started with a high K value of 0.48 $cmolkg^{-1}$ and decreased to 0.20 $cmolkg^{-1}$ on day three after incubation. The K value peaked on day 7 (0.38 $cmolkg^{-1}$) and decreased and increased as the day of incubation progressed until day 60 (0.28 $cmolkg^{-1}$). A similar pattern of results was exhibited by soil amended with inorganic fertilizer, having its highest value of K in day 7 (0.44 $cmolkg^{-1}$). However, the K value decreased on day 14 (0.32 $cmolkg^{-1}$), increased on day 21 (0.36 $cmolkg^{-1}$, and decreased from day 28 to day 42 before increasing, again, on day 60 (0.34 $cmolkg^{-1}$). For the soil amended with compost 1 (50:25:25), compost 2 (50:40:10) and compost 3 (50:50), their K values were high on day 0, decreased on day three and finally peaked on day 7 (0.38 $cmolkg^{-1}$, 0.39 $cmolkg^{-1}$, and 0.40 $cmolkg^{-1}$, respectively). The K value of the soil amended with compost 4 (100 *Sargassum*) increased from day 0 to day 7 (0.44 $cmolkg^{-1}$). The highest value of K was obtained on day 21 (0.44 $cmolkg^{-1}$) (Figure 6.7).

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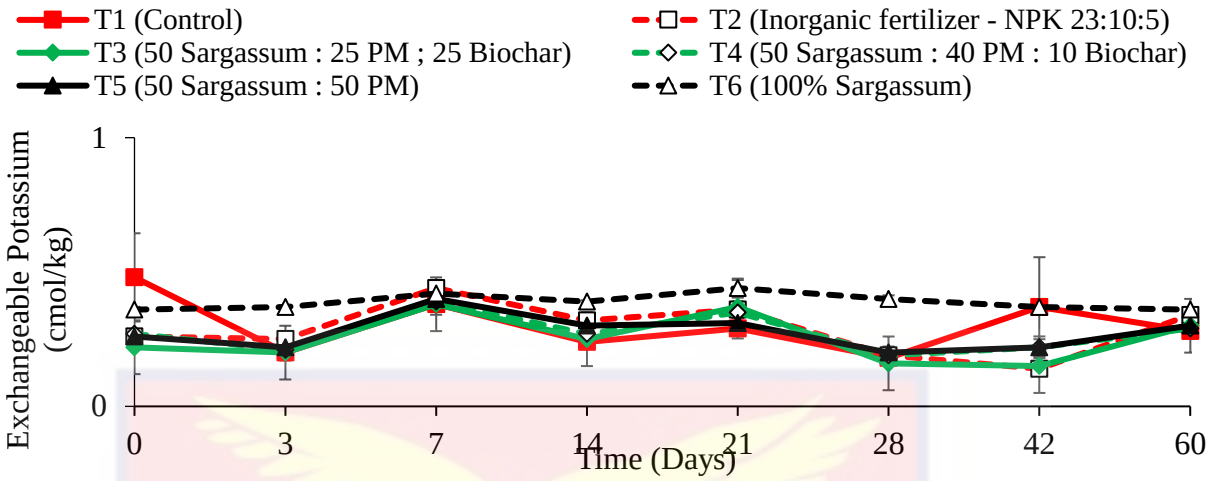


Figure 6.7: Influence of soil amendments mineralization on soil exchangeable potassium (K) dynamics after incubation. Data represents the mean of four (4) replicates with error bars representing standard error of the mean (S.E.M.)

Soil amendments mineralization and cation exchange capacity (CEC) dynamics

Significant (P = 0.01) differences existed in the effects of mineralization of soil amendments on the CEC of the incubated soil on days 0, 3, 7, 21, 28, 42, and 60. Furthermore, on day 14, a significant (P < 0.05) differences existed in the effects of mineralization of soil amendments on the CEC of the incubated soil (Figure 6.8). For soil without compost amendment, soil amended with inorganic fertilizer, compost 1 (50:25:25), compost 2 (50:40:10) and compost 3 (50:50), CEC values increased from day 0 to day 3 (3.28 $cmolkg^{-1}$, 2.67 $cmolkg^{-1}$, 2.43 $cmolkg^{-1}$, 3.92 $cmolkg^{-1}$ and 3.26 $cmolkg^{-1}$, respectively) (Figure 6.8). CEC values were reduced on day seven except for compost 2 (50:40:10), which increased in value. CEC values were reduced from day 14 to day 28 for the treatments above (1.71 $cmolkg^{-1}$, 1.37 $cmolkg^{-1}$, 1.59 $cmolkg^{-1}$ and 1.16 $cmolkg^{-1}$, respectively). From day 42 to day 60, all the treatments above experienced a rise in CEC values again. However, in compost 4 (100 *Sargassum*) there was a decrease in CEC values from day 0 to day 3 (3.72 $cmolkg^{-1}$). The CEC value reduced further from day 7 to day 14 (4.31 $cmolkg^{-1}$), then it increased from day 21 (5.29 $cmolkg^{-1}$) to day 42 (7.34 $cmolkg^{-1}$), which was also the peak value of compost 4

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(100 *Sargassum*), then it finally decreased in value on day 60 (5.96 cmolkg^{-1}) (Figure 6.8). For soil without compost amendment, the peak value occurred on day 3 (3.2 cmolkg^{-1}) and for soil amended with inorganic fertilizer, the peak value occurred on day 60 (3.16 cmolkg^{-1}). Meanwhile, for compost 1 (50:25:25), its peak value occurred on day 7 (4.13 cmolkg^{-1}), while for compost 2 (50:40:10), its peak value occurred on day 3 (3.92 cmolkg^{-1}). Furthermore, in soil amended with compost 3 (50:50), the highest value of CEC occurred on day 60 (3.94 cmolkg^{-1})

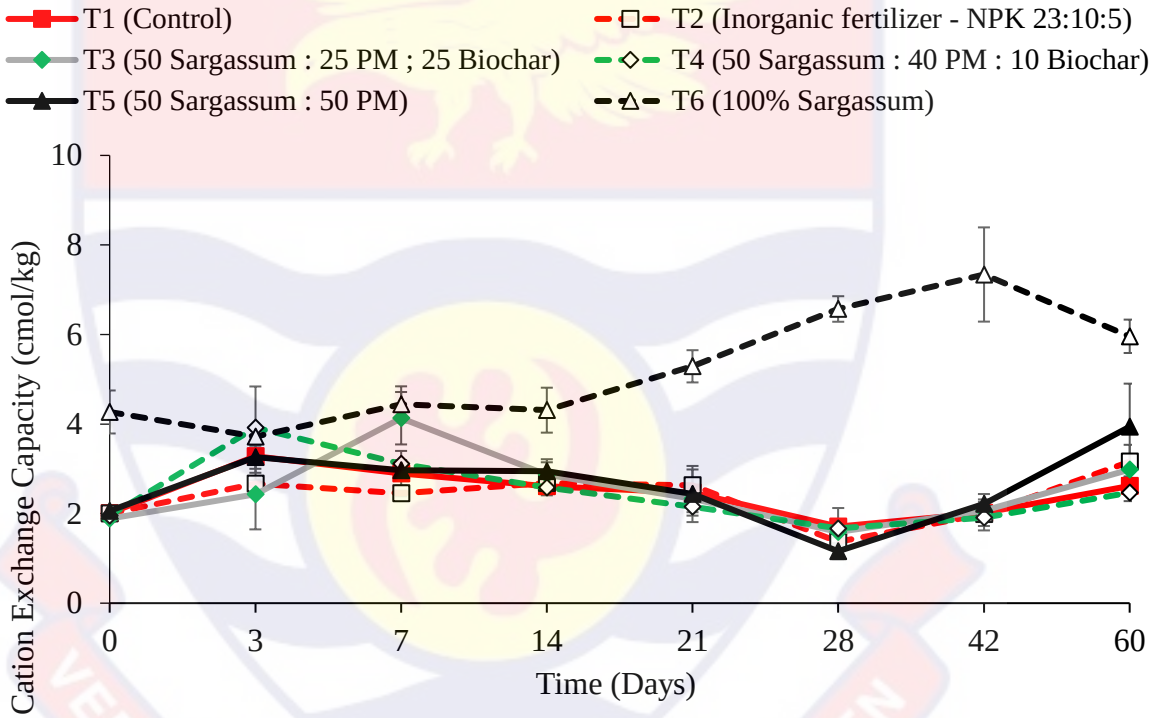


Figure 6.8: Influence of soil amendments mineralization on soil cation exchange capacity (CEC) dynamics after incubation. Data represents the mean of four (4) replicates with error bars representing standard error of the mean (S.E.M.)

Discussion

Physico-chemical properties of soil

Low crop output results from plants' inability to readily absorb applied or natural nutrients, especially phosphorus, when the pH is acidic. This phenomenon also slows down soil microbial activity (Haile *et al.*, 2009). The quick breakdown of organic waste caused by high temperatures, high humidity and intense sunshine may be the reason of

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the low level of organic carbon in this study (Amberger, 2006). Organic carbon (OC) is a key indicator of sustainable land management and affects how the soil reacts to N and P fertilizer (Bationo *et al*., (2007).

The effects of phosphorus availability in sandy loam soil were erratic, as previously reported in literature (Hirzel, Undurraga & Walter, 2010; Oehl *et al.*, 2004). These effects are linked to reactions that control the availability of P in soil (Chatterjee, Datta, & Manjaiah, 2014; Havlin *et al.*, 2016). According to Tisdale *et al*. (1990), soil response, clay mineralogy and fertilizer management all had an impact on the amount of phosphorus available in the soil. Long-term phosphatic fertilizer treatments have resulted in elevated P levels that surpass crop requirements, which present a challenge (DeLaune *et al.*, 2006).

Absorption of NH_4^+-N by root reduces Ca^{2+}, Mg^{2+} and K^+ uptake, while it increases absorption of H_2PO_3, SO_4^{2-} and CL (Lehmann, (2007). In this study, ammonium nitrogen was higher than nitrate nitrogen, implying that microbial activities in this soil were low, hence, there was less mineralization of organic matter. This work supports the findings of Amissah (2015) who observed that the soil of haplic acrisol was deficient in organic carbon and also agrees with Mensah & Frimpong (2018) who found that NO_3^--N and NH_4^+-N were the accessible forms of N for plant absorption.

Soil amendments mineralization and pH dynamics

According to the study, soil pH rose due to application of organic amendments as opposed to samples of unmodified soil. The increase in pH could be related to the alkalinity of plant residues, which formed base cations, while adding legume residue under varying soil moisture regimes (Albera *et al.*, 2012). This study contradicts those of Liyanage *et al.* (2015) who reported that nitrification would result in a drop in the soil pH. However, the study concurs with reports from Opala *et al*. (2012) and

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Robertson & Groffman (2007) who found that the ideal pH range for soil microbial oxidizers is 7.0–7.9. Numerous studies have reported that biochar's natural alkalinity could act as a liming agent, thereby increasing the pH of the soil, particularly to lessen the acidity of acidic soils (Tsai & Chang, 2020a; Tsai & Chang, 2020b; Tsai & Chang, 2020c; Jefferey *et al*., 2011; Yu *et al*., 2021).

During the first week of incubation, inorganic fertilizer added to sandy loam soil increased pH in comparison to the control. This, perhaps was related to the conversion of NH_2-N to NH_3-N and the following H^+ protons being taken up from the medium to change NH_3-N into NH_4^+-N, which raised the concentration of OH^- (Havlin *et al.*, 2016). According to research by Fageria & Nascente (2014) and Havlin *et al.* (2016), the quick conversion from NH_4^+-N to NO_3^--N may have caused the pH to drop in the sandy loam soil after applying the inorganic fertilizer.

Effects of pH on nitrogen, phosphorus and potassium mineralization

One of the main elements influencing the N cycle, which includes mineralization is the pH of the soil (Sahrawat, 2008; Curtin & Trolove, 2013). It has been documented that nitrification may occur in severely acidic soil (Head *et al.*, 1993; DeBoer & Kowalchuk, 2001; Gubry-Rangin *et al.*, 2010; Haynes, 2000), which fits with this current study having a soil pH of 6.49 (Table 6.1).

According to Liang *et al.* (2006), pH values higher than 7.5 encouraged nitrogen loss by ammonia volatilization. The results support those of Rigby *et al.* (2016) who found that when pH values were elevated between the acidic and slightly alkaline range (<pH 8), the N mineralization rates increased in soil supplemented with compost.

Soil amendment mineralization and electrical conductivity (EC)

The EC values in the sandy loam soils were below the agronomic critical level, meaning that they pose no threat to agriculturally cultivated species. EC values

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increased across the board for all treatments (Havlin *et al.,* 2016). This study supports the results of Hirzel *et al*. (2023) who discovered that adding three different types of compost to sandy loam soils increased the EC value in a comparable way. The concentration of free ions in the solution was lowered because of the expansion of soil biomass and its involvement in physico-chemical processes between free ions and carbon bonds (Hirzel, Undurraga & Walter, 2010; Hartz *et al.,* 2000. Additionally, compost 4 had high EC values, possibly as a result of the *Sargassum* spp. being composted without any additives to balance out their saline content.

Soil amendments mineralization and Ammonium nitrogen (NH_4^+-N)

In this study, the NH_4^+-N concentration of the soil that had been treated with composts increased initially. The mineralization of biological substances may be the cause of this. Therefore, a major determinant regulating the amount of N supplied to crops is the rate at which organic N breaks down and mineralizes into inorganic N (Zhang *et al.,* 2015). According to Hossain *et al.* (2017), temperature, soil moisture content and fertilizer type (either chemical or organic) all affect the N mineralization process. The resilience of heterotrophic bacterial activity may be responsible for the rapid ammonification (Abera *et al.,* 2012). According to Liyanage *et al.* (2021), certain compost-amended soil exhibited a rapid breakdown and mineralization process due to its reduced carbon-to-nitrogen ratio and higher N content. The findings of Baldi & Tosseli (2014) who found a similar tendency of incubation of compost supplemented soil, are corroborated by this study. However, the results of Walpola & Arunakumara (2010) who stated that the NH_4^+-N content peaked at day 15 and then gradually decreased in all treatments, are not supported by the results of this study. Depending on the prevailing unfavourable soil condition, the ammonium mineralized from organic amendments may be lost as NH_3 (g) and later converted into nitrate, or trapped by soil

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components or momentarily immobilized by soil microbes (Azeez & van Averbeke, 2010). The alternative hypothesis is, thus preferred to the null hypothesis.

Soil amendments mineralization and nitrate nitrogen (NO_3^--N)

In various aquatic and terrestrial habitats, nitrification is done by a restricted group of nitrifying chemo-lithotrophic bacteria and archaea, where ammonium ions (NH_4^+-N) are oxidized to nitrate (NO_3^--N) (Head *et al.,* 1993; De Boer & Kowalchuk, 2001). Since plants prefer to absorb NH_4^+-N and NO_3^--N, this process is crucial if nitrogen should be made available to plants in the soil. During the seven days of mineralization, 84% of the treatments showed rapid N mineralization. The results of the study run counter to those of Ling-ling & Shu-tian (2014) who found that after 56–84 days of incubation, manure-treated soil quickly mineralized nitrogen. Mostly, NO_3^--N undergoes more nitrification than denitrification, according to the findings of Abera *et al.* (2012).

Effects of biochar on nitrogen mineralization, immobilization and nitrification

Nitrification values in the co-composted biochar were lower than ammonification values. This probably might be due to biochar adsorption of NO_3^--N or immobilization by microbes (Clough *et al*., 2013). Biochar influences the soil N cycle through: (1) N adsorption or desorption by biochar to change the amount of inorganic N in the soil; (2) modifications to the content of soil mineralizable substrates (i.e., labile organic compounds) to influence the microbial processes of N mineralization or immobilization; and (3) changes to soil pH and aeration in order to change the equilibrium between nitrification and denitrification processes (Dai *et al.,* 2020). Because of its surface's labile carbon and acid functional groups, low- temperature biochar often adsorbs more NH_4^+-N than high-temperature biochar (Nguiyen *et al.,* 2017). This is especially true for biochar that is pyrolyzed at lower temperatures.

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Furthermore, there is no discernible trend in the pyrolysis temperature, although ammonium removal rates exhibit significant variations of feedstock and pyrolysis temperature (Yao *et al*., 2012).

Soil amendments mineralization and C:N ratio

The C:N ratio in this study had increased on the loamy sandy soil, which suggested that immobilization was higher than mineralization by microorganisms. The results of the study aligned with those of Islami *et al.* (2011) who found that compost immobilization reduced soil nitrogen availability.

The NH_4^+-N content was reduced in the co-composted biochar. Chen *et al*. (2021) concluded that the reduced NH_4^+-N was due to adsorption into charcoal rather than microbial immobilization (Masunga *et al.,* 2016). There have been reports of N immobilization after adding biochar or compost (Ameloot *et al*., 2015; Hailegrow *et al.,* 2019; Signa *et al*., 2016).

One possible explanation for the decrease in total nitrogen in the soil could be that the high C:N ratio of the biochar utilized in the study caused nitrogen to get immobilized. This is because there was initially a net immobilization of nitrogen (Borchard *et al.,* 2012) when biochar's C:N ratio approached 20 (Nguiyen *et al.,* 2017; Chan & Zu, 2009) and/or 32 (Nguiyen *et al.,* 2017; Kuzyakor *et al.,* 2000). This is the general mechanism by which N immobilization occurs. Contrary to the results of the compost examined in the current experiment all the composts analyzed had a C:N ratio of less than 20 (Eldridge *et al.,* 2017).

Soil amendments mineralization and available phosphorus (P)

Day 14 of this study showed a sharp decrease in P when compost was used. This could be attributed to a colloidal clay-humus complex formation (Havlin *et al.,* 2016; Chatterjee, Datta, & Manjaiah, 2014) as well as organic phosphorus as non-labile

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phospholipids, inositol and orthophosphate diesters, which were more resistant to any breakdown (Silveira, Miyittah, & O'Connor, 2006; Dao, 2004; Silveira *et al.*, 2005). P could be sharply reduced as a result of the released P being re-adsorbed into biochar and immobilized by microorganisms (Chen *et al.*, 2021).

Furthermore, because adsorbed biochar has a higher pH and more microbial activity, it can lower P in compost and apart from the immobilization of microorganisms, the mineralized component of P could have been bonded back into organo-complexes (Jalali *et al.*, 2014). The results of this study deviate from those of Naher *et al*. (2004) who discovered increased P mineralization in compost treated with chicken manure and cattle manure.

Biosolids (also known as wastewater products or MSW) P mineralization and immobilization in soil have positive environmental and soil nutrient amendment inputs, according to Ahmad *et al.* (2019). Because of the simultaneous mineralization-immobilization process, microbial P immobilization rendered soil P temporarily unavailable to plants, but it can be made available upon full microbial decomposition of organic waste (Kirkby *et al.*, 2014; Johnson, 2012). Zhang *et al*. (2020) reported that P fertilizer increased the organic matter (OM) cycle, potentially enhancing soil carbon sequestration in paddy soils.

Soil amendments mineralization and exchangeable potassium (K)

The results of this study indicated an increase in K levels after incubation. This study, however, deviates from the findings of Hirzel *et al.* (2023), which reported smaller values of K on day 0 of their 120-day incubation in sandy loam soil. It was reported in literature that when compost was used there was an increase in K concentration (Bustamante *et al.*, 2011; Jiménez Becker *et al.*, 2010), Nevertheless, research has shown that clay loam soils have a high potential for K fixation (Havlin *et*

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al., 2016; Chatterjee, Datta, & Manjaiah, 2014). Moreover, the higher K efficiency value in the soil indicated a faster K delivery from the organic fertilizer during incubation (Havlin *et al.*, 2016; Portela *et al.*, 2019).

The current study found that there was a high concentration of NH_4^+-N on day seven, coinciding with an increase in K^+. Thus, one may claim that decreased NH_4^+-N fixation was caused by the elevated K^+ concentration. According to Samuel *et al.* (2003), because K^+ can also fill fixation sites, its presence frequently restricted ammonium nitrogen

Soil amendments mineralization and Cation Exchange Capacity (CEC)

The present study's treatments exhibited the capacity to retain and exchange cations, including K, Na, Mg and Ca necessary for plant absorption, as CEC is a crucial characteristic of soil. Compost 4 (100 *Sargassum*) recorded the highest CEC value in this study, despite the fact that all soils amended with compost containing poultry manure were significantly higher than the control (soil without compost). This raises questions about whether the initial poultry manure inculcated in the composting material had any major role to play in increasing CEC. Given that the soil's organic matter content and pH (pH =7.1) are the parameters that regulate CEC, the CEC on day 42 may have increased due to these causes. This study is consistent with the findings of Sartor *et al.* (2012) and Ano & Agwu (2005) who reported that there is a link between CEC and TC.

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Conclusion

With the exception of compost 4 (100 *Sargassum*), all treatments had the highest pH on the seventh day after incubation during the mineralization of soil additions. On day 0 of incubation, electrical conductivity peaked and then declined until day 60. The values of nitrate nitrogen (NO_3^--N) and ammonium nitrogen (NH_4^+-N) peaked on the seventh day of incubation and thereafter declined until the sixtieth day. The highest NH_4^+-N: NO_3^--N value was lowest on incubation day seven, except for compost 4 (*Sargassum*), indicating compost maturity. The C:N ratio was lowest in value on incubation day 28, except for soil amended with inorganic fertilizer and compost 2 (50:40:10). The highest P, K and CEC values were released by compost 2 on incubation day 7. The results of the soil amendment mineralization showed that incubation day 7 showed prominence, whereby the highest N, P and K released will meet the critical point of the plant.

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CHAPTER SEVEN

EFFECTS OF SARGASSUM COMPOST ON GROWTH AND YIELD OF OKRA IN COASTAL SAVANNAH ACRISOL SOIL

Introduction

Okra (*Abelmoschus esculentus* (L.) Moench) is the most consumed crop in sub–Saharan Africa (Singh *et al*., 2003). Okra has gained popularity globally due to its export potential, the possibility for year-round cultivation, high nutritional value and medicinal properties (Elkhalifa *et al*., 2021). While the roots and stems are used as a clarifying agent for brown sugar preparation, the crude fibre in the mature fruits and stems is a source of useful raw materials for paper production (Muhammad *et al.*, 2020; Joshi *et al*., 2021). According to the Food and Agriculture Organization statistics division in the United States FAOSTAT (2020), approximately 10.5 million tons of okra are produced globally. India leads the world in production in okra, accounting for about 60.4%, followed by Nigeria, which contributes approximately 17.4%, and Ghana, ranking ninth with approximately 67000 tons (FAOSTAT, 2020). Okra is a key ingredient in food preparation and is the fourth most extensively grown vegetable in Ghana, behind pepper, tomatoes, and garden eggs (Oppong Sekyere *et al.*, 2012). Growing on sandy loam and loam soils, which can eventually become deficient in N, P, K, Mg and B is how most okra is produced in Ghana and other West African countries (Tisdale & Nelson, 1978). There are drawbacks to using inorganic fertilizers in crop production such as soil acidification, nutrient imbalances, and deficits in trace elements, particularly zinc and magnesium (Asadu, 2004). According to Storey (1995) and Epstein (1997) compost comprised comparatively stable decomposed elements that are the product of rapid biological decomposition of organic matter in regulated aerobic circumstances. Smallholder vegetable producers can easily make compost by allowing

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bacteria in a wet, warm and aerobic atmosphere to partially decompose locally accessible organic materials (Raabe, 2001). Compost made from decomposing plant leftovers is said to release significant quantities of organic matter and nutrients into the soil (Yih-Chi *et al*., 2009). Since compost materials are readily available and reasonably priced, using them to produce vegetables can reduce production costs, which could boost the incomes and livelihoods of smallholder farmers (Akanbi *et al*., 2004).

Moreover, compost releases nutrients in quantities that are balanced to avoid excessive gaseous and leaching losses and maintain crop uptake in rhythm with nutrient availability (Badejo & Togun, 1998). The use of compost not only preserves soil fertility, but also improves food quality and enhances crop growth on heavy metal-contaminated soils by mitigating the effect of heavy metals on crops (Rennevan *et al.,* 2007; Fleming *et al.,* 2010; Adejumo *et al.,* 2013). Additionally, compost originated from plants and animals has been found to increase the yield of crops grown on nutrient-depleted or deficient soils (Rennevan *et al.,* 2008; Adejumo *et al.,* 2010; Fleming *et al*., 2010; Basu *et al*., 2011). Compared to raw organic matter, mature compost offers a stable form of organic matter and may improve soil nutrient release (Adediran *et al.,* 2003). Thus, the purpose of this chapter was to assess how well *Sargassum* spp. composts affected the vegetative growth and fruit yield of okra.

Objective

To evaluate *Sargassum* spp composts of varying compositions on the growth and yield of okra.

Hypothesis

Ho: The growth and yield performance of okra grown with *Sargassum* spp. composts are not different.

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H_1: The growth and yield performance of okra grown with *Sargassum* spp. composts differ.

Materials and methods

Site description of pot experiment

The Alexander G. Carson Technology Centre (ACTC) of the University of Cape Coast, located in Cape Coast (latitude 05º7'47.07"N and longitude 01º17'14.58' W), was the site of the pot experiment for okra production. According to the textural class determination, the region's soils are sandy clay loam. The soil is part of the Edina-Benya-Udu compound association, which is a component of the Benya series, and was formed from Sekondian material. The humid coastal savannah agroecological zone, with an average yearly rainfall of 1400 mm and an average temperature of 26.5 °C, is the location of the soil sample. Haplic Acrisols are soils that are grown on sandstones, shales and conglomerates, according to FAO/UNESCO (IUSS Working Group WRB, 2015).

Effects of *Sargassum* compost on growth and yield of okra during pot experiment

Two pot experiments were conducted. The first experiment started from 5th February to 14th May, 2023, while the second experiment started from 28th May to 6th September, 2023. Within the Alexander G. Carson Technology Centre, UCC, four replicates of 72 pots multiplied by two (144 pots) were set under a rain shed as part of a 3 x 6 factorial experiment fitted into a Randomized Complete Block Design (RCBD). The first factor included three varieties of okra (Clemson spineless, Indiana and Volta), while the second factor included six levels of soil amendment. The experimental design used is represented in Figure 7.1.

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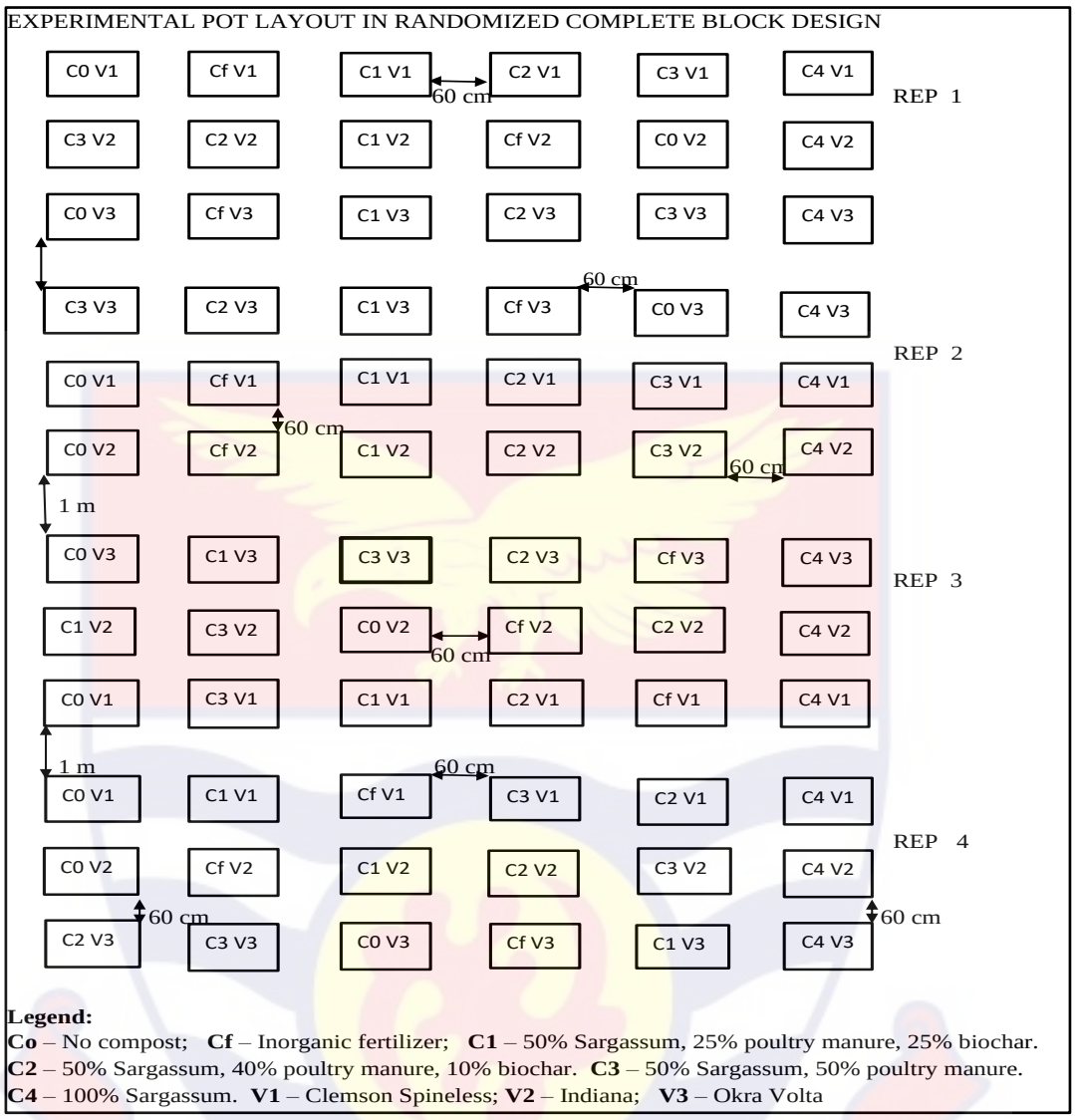


Figure 7.1: Sample randomization of treatments in experimental layout

Top soils were gathered from the study site, sieved through 2mm mesh to get a fine texture and used to fill the plastic pots (28 cm high, 27 cm wide at the top and 20 cm at the base) of volume 12419.12 cm^3. The bases of the pots were perforated with four holes, each with a diameter of 0.7 cm, to let excess water to drain and gather in sauce that was placed underneath each plastic pot. As determined in chapter 6, the bulk density of the soil in each pot was 1.3 g cm^{-3}, and the soil's weight was 16 kg.

The compost was then measured using an electronic weighing balance (RoHS, A & D Company, Ltd. Korea). The levels of soil amendments were as follows: T1 (soil

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without compost), T2 (inorganic fertilizer made of NPK 23:10:5, Urea (46% N), Muriate of Potash (60% K_2O) & Tripple superphosphate (46% P_2O_5), compost 1 (T3 = 50% *Sargassum*, 25% biochar and 25% poultry manure), compost 2 (T4 = 50% *Sargassum*, 40% poultry manure and 10% biochar), Compost 3 (T5 = 50% *Sargassum* and 50% poultry manure) and compost 4 (T6=100% *Sargassum*). To get the corresponding rates of compost/ha, the amounts of compost applied in each pot were Compost 0 (T1 = control), Compost 1 (T3 = 34,918.6 kg/ha = 432.35 g for 16 kg soil), Compost 2 (T4 = 32,290.4 kg/ha = 414 g for 16 kg soil), Compost 3 (T5 = 30,958.80 kg/ha = 530.37 g for 16 kg soil) and compost 4 (T6 = 33,000.03 kg/ha = 404.5g for 16 kg soil). The 16 kg of soil in the pot was thoroughly mixed with each compost rate. A sauce-pan was placed under each pot to catch the leachates once the pots were filled with water to the field's capacity.

Before planting, the soil/compost mixture was incubated for two weeks to allow the compost to acclimate to the soil in the pots. Okra seeds from the *Clemson spineless* (V1), Indiana (V2) and Volta (V3) purchased from Agri Seed, Ghana Ltd, Accra, were used. The okra seeds were primed for three hours before planting (sowing). Percentage germination of *Clemson spineless* and Indiana were higher than okra Volta. After a week, when every plant had at least two leaves, four seedlings were thinned out of each pot to one plant. 60% of the soil's water-filled pore spaces (WFPS) were preserved during the research period by weighing.

Description of the test crops used in the experiment

Volta Okra

West Africa, namely Cote d'Ivoire, is home to the Volta okra cultivar. The Volta River, which flows through Ghana and Togo, is the source of its name. It produces long, thin, ribbed fruits. Its high quantities of protein, fat, phenolic compounds and vitamin

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C are among its well-known nutritional qualities. It is a desirable crop for both local consumption and possible export markets because of these qualities. About 60 days after direct seeding, it reaches maturity and reaches a height of about 60 cm (infonet-biovision.org). Pods are lengthy; they are around 2 cm in diameter and 16–18 cm long. The medium-green pods show excellent disease resistance and vigorous growth.

Indiana

The Indiana okra cultivar was created for the Indian subcontinent and is distinguished by its disease resistance and impact growth. About 60 days after direct seeding, it reaches maturity and reaches a height of about 60 cm (infonet-biovision.org). Pods are lengthy; they are around 2 cm in diameter and 16–18 cm long. Pods are medium green in color and have a high level of disease resistance.

Clemson spineless

West Africa, namely Cote d'Ivoire, is home to the Volta okra cultivar. The Volta River, which flows through Ghana and Togo, is the source of its name. It produces long, thin, ribbed fruits. Its high quantities of protein, fat, phenolic compounds and vitamin C are among its well-known nutritional qualities. It is a desirable crop for both local consumption and possible export markets because of these qualities.

Cultural practices

Watering was done three times each week using a 10 ml beaker. Two weeks following sowing, 1.2307 g of NPK compound fertilizer (23:10:5) per 16 kg of soil, 0.41024 g of muriate of potash (60% K_2O) and 0.5352 g of triple super phosphate (46% P_2O_5) per pot were added. Urea (46%N) was applied as a second split at 0.7224 g per pot six weeks after planting. Whenever necessary, routine weed control was done.

Two weeks after emergence, 3 mL of Bonlambda and Bon Optimal put in 40 ml knapsack sprayer, sprayed every two weeks, were used as a control measure against flea

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beetles (*Podagrica* spp.), aphids, white flies and other pests. Sometimes, the *Podagrica* spp. were handpicked on the leaves of the plants and killed.

Viral diseases were also controlled using 5-star chemicals. During the flowering and fruiting stages of the crop, the insecticide was changed to Sunpyrifos to control pests. Fungal diseases were controlled with Topsin fungicide, applied biweekly at 2 g/l. In the sixth week, the fungicide was changed to Carimho 50, a systemic fungicide for the control of fungal diseases on vegetables, which was also applied using a knapsack sprayer at a rate of 2 g L^{-1} of water.

Data collection

Data were collected 3 WAP, 4 WAP, 5 WAP, 6 WAP, 7 WAP and 8 WAP (WAP =Weeks After Planting). Plant height, stem diameter, length, width and number of leaves per plant, petiole length and internode length were all examples of morphological data taken. Leaf chlorophyll content was also taken as physiological data. A transparent plastic ruler was used to measure the plant's height, petiole length and leaf area. When the plants had grown past the length of a plastic ruler, their height was measured from the surface of the soil to their apical tip using a meter rule.

To calculate the leaf area, a transparent plastic ruler was also used to measure the length and width of leaves. In order to calculate the leaf area, the length (L) and maximum width (W) dimensions of the leaf were measured and inserted into the equation, Leaf area = $0.34(LW)^{1.12}$ as reported by Omolaiye *et al.* (2015). A digital vernier caliper was used to measure the plant's stem diameter 1 cm above the soil's surface, and the number of fully grown leaves were counted and recorded. The internode and petiole lengths were measured with a clear plastic ruler. The amount of chlorophyll in leaves was measured using a Soil Plant Analysis Development (SPAD) Chlorophyll meter (SPAD-502 Plus, Konica Minolta Spectrum Technologies Inc., Aurora, IL,

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USA). The days to first flowering, days to 50% flowering, number of pods plant^{-1}, weight of a single fruits plant^{-1}, and weight of all the fruit plant^{-1} were among the phenological yield and yield components data. Every day, flowers were observed and counted, and throughout the blossoming season, they were tagged. Days to first flowering were noted, numbered and recorded.

The days to 50% flowering were established after at least half of the plants in two replications of the same treatment, flowered. Every four days after anthesis, the fruits were harvested with a sharp knife and placed in a brown labelled envelope for additional research. Fruit quality data included fruit length and diameter, and the quantity of seeds plant^{-1}. The length, and diameter of fruit were measured using a transparent plastic ruler and electronic vernier calliper, respectively. Fruit per plant was sampled and sliced transversely and longitudinally using a sharp razor blade to examine the locules and number of the seeds per fruit. Matured fruits and seeds of the different varieties of okra are represented in Figure 7.2

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Figure 7.2: Okra fruits and seeds: (a) Clemson spineless variety (b) Indiana Okra variety (c) Volta Okra variety

Dry matter accumulation

At the end of the experiment, a sharp knife was used to cut the shoot away from the root. The shoot per each treatment was enveloped and taken to the laboratory for weighing. Later, excavation was done to expose the plant's root using a water hose. The root was also bagged in labelled brown envelopes for a similar treatment as the shoot in the laboratory. In the oven, the fresh shoots and roots were dried to a consistent weight at a temperature of 65^{o}C for three days. On the fourth day, they were removed from the oven, weighed and recorded.

Statistical analysis

To ascertain the significance of the data, general analysis of variance (ANOVA) was carried out using GenStat Twelfth Edition, Procedure Library Release PL20.I, 2009

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(VSN International Limited, Rothamsted Experimental Station, Hemel Hempstead, UK). R Statistical software was utilized to create the graphical representation of the data, and Tukey's Honestly Significant Difference (HSD) and Fisher's protected Least Significant Difference test at 5% probability level were employed to separate the means.

$Y_{ijk} = \mu + v_i + c_j + r_k + vc_{ij} + \varepsilon_{ijk}$ .....[7.1]

Where Y_{ijk} = observation from the ijk^{th} okra variety, compost and replication, μ = overall mean, v_i = effect of the i^{th} okra variety, c_j = effect of the j^{th} compost, r_k = effect of the k^{th} replication, vc_{ij} = interactive effect of the i^{th} okra variety with the j^{th} compost, and ε_{ijk} = experimental error.

Results

Germination percentage of okra seed in the first and second trials

The *Sargassum* compost significantly (P = 0.05) influenced the percentage of seed germination of okra varieties in the first trial (Figure 7.3).

Nevertheless, the interaction impact between variety and compost did not change significantly (P > 0.05) (Figure 7.3). Percentage of seed germination ranged from 85.4%-97.9%, with compost 3 (50:50) recording the highest percentage of seed germination, followed by soil amended with inorganic fertilizer (95.8%). Concerning okra varieties, Clemson spineless and Indiana appeared better, obtaining the highest percentage of seed germination value at 95.8% (Figure 7.3). Regarding the interaction effect between compost and variety, Indiana appeared to be the best, recording 100% in soil with no compost. Clemson spineless also recorded 100% seed germination in soil amended with inorganic fertilizer, compost 3 and compost 4 (Figure 7.3).

In the second trial (Figure 7.3), the effect of *Sargassum* spp. compost significantly (P=0.01) influenced the percentage of germination of the okra varieties. In okra varieties, Indiana and Clemson spineless obtained the 1st and 2nd highest

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germination percentage of 96.9% and 95.8%, respectively. There was no significant variation in compost or in the interaction between compost and variety (P > 0.05) (Figure 7.3). The highest percentage of seed germination occurred in compost 3 (50:50) (95.8%), followed by compost 2 (50:40:10) (93.8%). In the interaction between compost and variety, Clemson spineless maintained its superiority by recording 100% percentage of seed germination in 4 out of the six treatments (Figure 7.3).

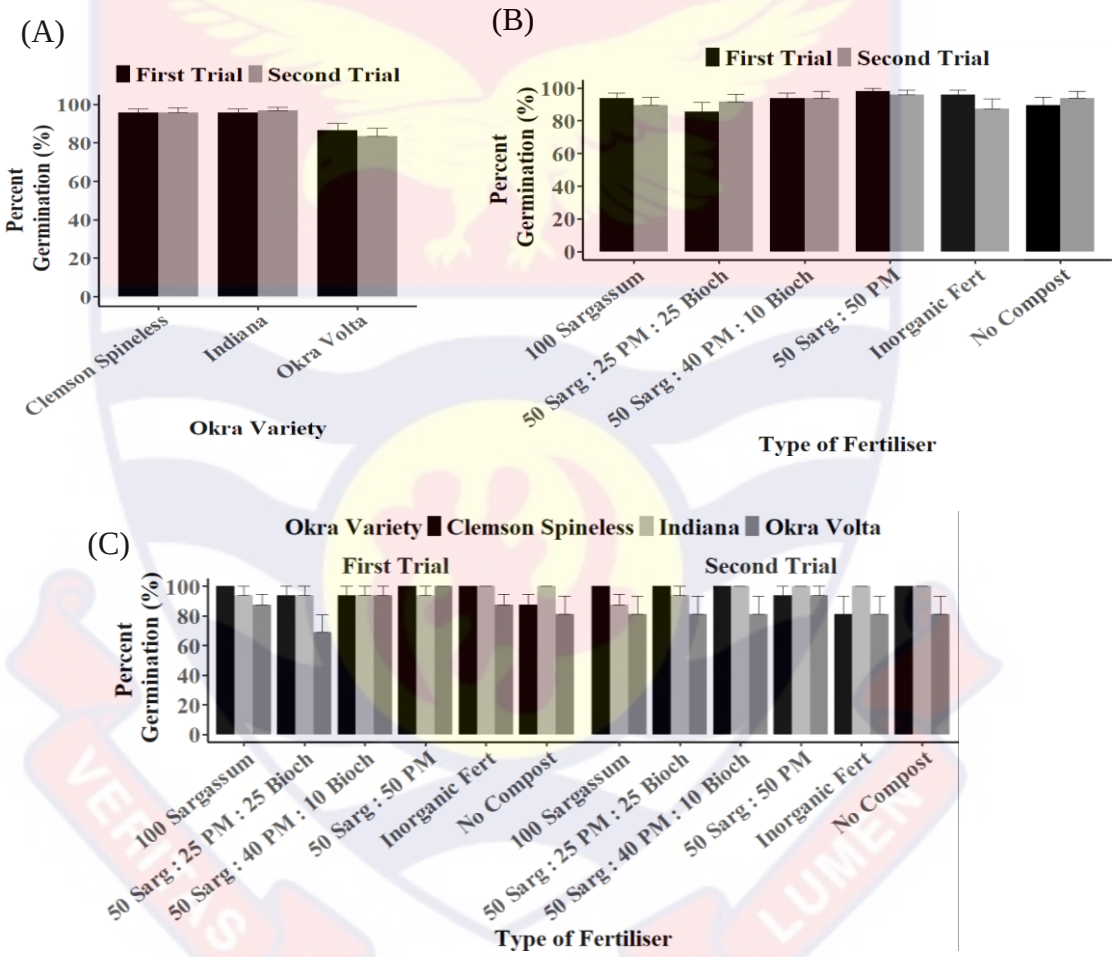


Figure 7.3: Effects of *Sargassum* compost of varying composition on percentage okra seed germination in pot studies in A & B (main effect) and C (Interactive effect) for 1st and 2nd trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on plant height of okra (First and second trials)

The *Sargassum* compost significantly (P=0.01) influenced the height of plant of okra (Figure 7.4). In the first trial, a significant difference (P=0.01) existed among

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compost for all treatments at 3, 4, 5, 6, 7 and 8 weeks after planting (WAP). (Figure 7.4). For soil without compost, plant height averaged 30.6 cm. Compost 2 (50:40:10) appeared best recording the highest mean plant height of 46.1 cm followed by compost 3 (45.5 cm) (Figure 7.4). Regarding varieties, a significant difference (P =0.01) existed from 3 to 8 WAP for all the treatments. Okra Volta obtained the highest mean value for plant height (43.7 cm) followed by Clemson spineless (40.1 cm) and Indiana (38.05 cm). Regarding compost-variety interactions, significant differences (P <0.05) existed in 3 WAP while from 4 WAP to 8 WAP plant heights were statistically similar. Okra Volta maintained its highest record of plant height in soil amended with inorganic fertilizer (45.8 cm), compost 1 (46.6 cm), compost 2 (49.7 cm), and compost 3 (51.2 cm) while Clemson spineless recorded the highest mean plant height in control (38.8 cm) and compost 4 (37.0 cm) (Figure 7.4).

In the second trial, *Sargassum* compost significantly (P=0.01) influenced plant height of okra from 3 to 8 WAP (Figure 7.4). Significant differences existed between 3 and 8 WAP for compost 1 (50:25:25), compost 2 (50:40:10) and compost 3 (50:50) (Figure 7.4). Compost 2 obtained the highest mean plant height (36.4 cm), followed by compost 1 (35.7 cm) compared to the control (23.7 cm) (Figure 7.4). Concerning okra varieties, there was a significant difference (P<0.05) between Clemson spineless and Indiana and okra Volta in 7 WAP. Clemson spineless obtained the highest mean plant height (24.9 cm) followed by Indiana (23.1 cm). However, there was no significant difference (P>0.05) among compost, with variety interactions from 3 to 8 WAP. Okra Volta obtained the highest plant height mean in soil amended with inorganic fertilizer (31.7 cm), compost 1 (37.9 cm), compost 3 (38.2 cm) and compost 4 (29.7 cm).

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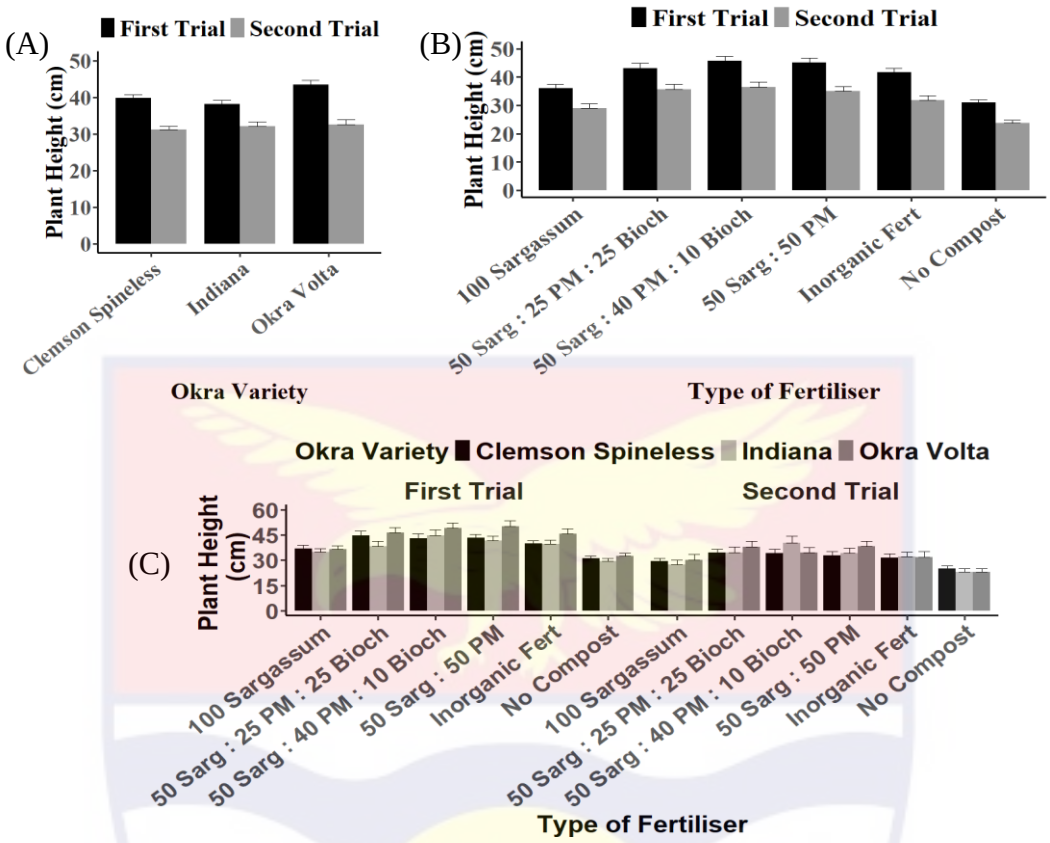


Figure 7.4: Effects of *Sargassum* compost with varying composition on plant height in pot studies A and B (main effect) and C (Interactive effect) for the first and second trials. Data represents the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on the number of leaves of okra (First trial)

The *Sargassum* compost significantly (P=0.01) influenced the number of okra leaves from 3 to 8 WAP in the first and second trials (Figure 7.5). In the first trial, significant differences (P=0.01) existed in all the compost treatments. While composts 2 (50:40:10) and 3 (50:50) recorded the highest leaves mean number (13.6) compost 1 (50:25:25) recorded the second highest mean leaves (13.3). Significant (P=0.05) differences existed between the okra varieties in 4, 6 ,7 and 8 WAP. Okra Volta recorded the highest number of leaves (13.1) followed by Indiana (12.6). There was a significant difference (P=0.05) in 3 WAP concerning compost and variety interactions. Okra Volta recorded the highest mean value of leaf numbers (10.0) in soil without compost,

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inorganic fertilizer amended soil (13.0), compost 1 (14.3), compost 3 (13.9) and compost 4 (12.6) (Figure 7.5).

The *Sargassum* compost significantly (P=0.01) affected the number of okra leaves from 3 to 8 WAP in the second trial (Figure 7.5). Significant differences (P=0.01) existed among compost treatments. Compost 2 recorded the highest okra leaf number of 11.9 followed by compost 3 (11.7) (Figure 7.5). Okra Volta recorded the highest number of leaves (11.6) followed by Indiana (10.7), No significant differences existed in the interaction between compost and variety on 3 to 8 WAP. Okra Volta recorded the highest mean number of leaves in control (7.7), compost 1 (12.2), compost 2 (12.7), compost 3 (12.6) and compost 4 (10.9) (Figure 7.5).

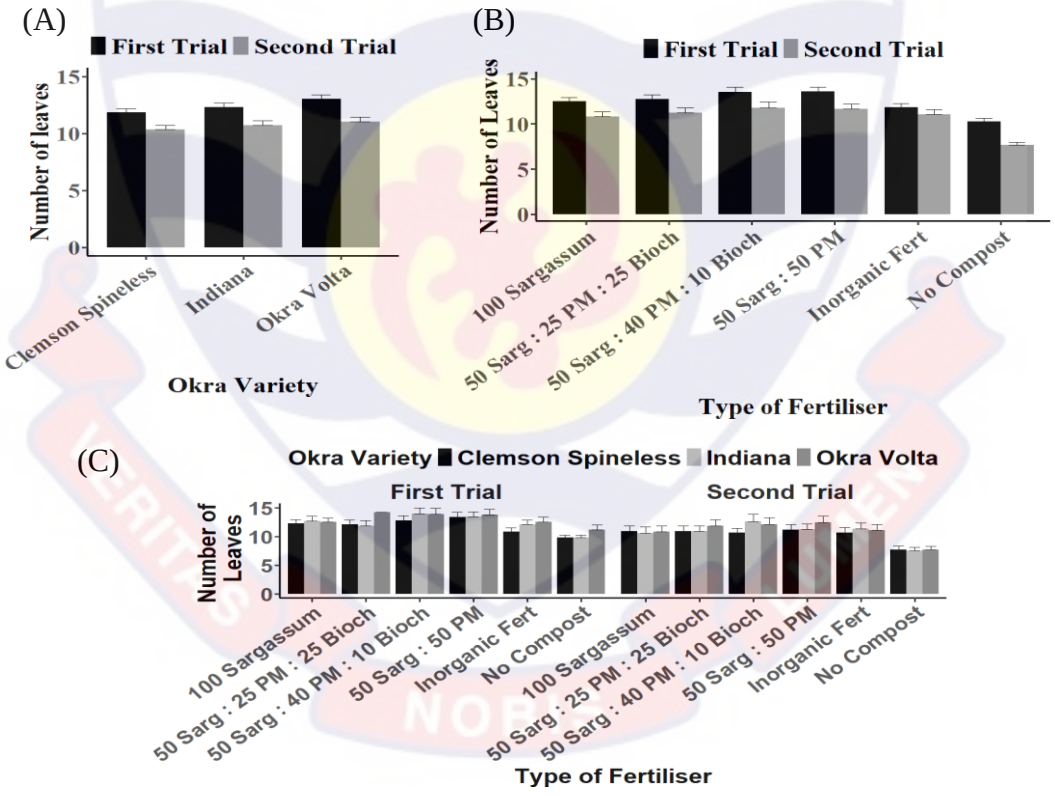


Figure 7.5: Effects of *Sargassum* compost with varying composition on the number of okra leaves in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

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Effects of *Sargassum* compost on internode length of okra (First and second trials)

The *Sargassum* compost significantly (P=0.01) affected the internode length of okra from 3 to 8 WAP in the first and second trials (Figure 7.6). With regards to compost, significant differences (P=0.01) existed among the composts from 3 to 8 WAP in the main experiment. Compost 3 (50:50) recorded the highest mean internode length (6.68 cm) followed by compost 2 (50:40:10) (6.58 cm). With regards to okra varieties, significant differences (P=0.01) existed among the okra varieties from 5 to 8 WAP. Clemson spineless recorded the highest mean internode length (4.43 cm) followed by okra Volta (4.38 cm). All the treatments were statistically similar, regarding compost and variety interactions. Okra Volta maintained its superiority by recording the highest internode length in soil amended with inorganic fertilizer (6.70 cm), compost 1 (6.77 cm), compost 2 (7.15cm), compost 3 (7.98 cm) and compost 4 (7.42 cm) (Figure 7.6).

The *Sargassum* compost significantly (P=0.01) influenced the internode length of okra from 3 to 8 WAP in the second trial (Figure 7 6). Compost 2 performed best averagely recording 6.55 cm followed by compost 1 (50:25:25) (6.53 cm). Significant differences (P=0.01) existed in okra varieties. Internode length in okra varieties ranged from 5.88 cm in Clemson spineless to 6.23 cm in okra Volta. A significant difference (P=0.01) existed at 8 WAP concerning compost and variety interaction. Okra Volta recorded the highest internode length in soil amended with inorganic fertilizer (6.53 cm), compost 1 (7.23 cm), compost 2 (7.08 cm), compost 3 (6.85 cm) and compost 4 (6.20 cm) (Figure 7.6).

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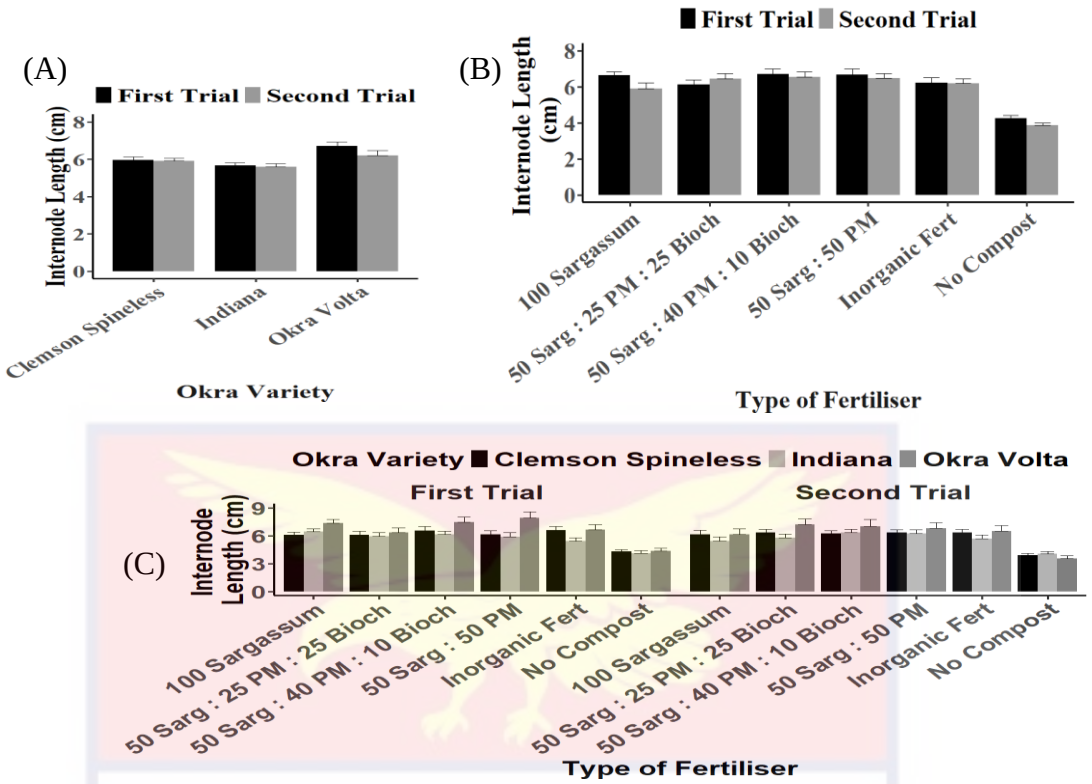


Figure 7.6: Effects of *Sargassum* compost with varying composition on internode length of okra in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on petiole length of okra (First and second trials)

The *Sargassum* compost significantly (P=0.01) influenced the petiole length of okra from 3 to 8 WAP in the first and second trials (Figure 7.7). Significant differences (P=0.01) existed in the compost varieties during the first trial. Compost 2 (50:40:10) recorded a mean petiole length (13.10 cm) followed by compost 1 (50:25:25) (12.90 cm). In 4 to 8 WAP, a significant difference (P=0.01) existed among the three okra varieties (Figure 7.7). Okra Volta appeared best when the highest mean value of petiole length (12.58 cm) followed by Clemson spoineless (10.82 cm) was recorded. Regarding the compost and variety interaction, no significant difference (P>0.05) existed in all the treatment means from 3 to 8 WAP. Okra Volta again appeared best recording the highest mean value of petiole length in control (8.35 cm), soil amended with inorganic fertilizer

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11.95 cm), compost 1 (15.03 cm), compost 2 (14.53 cm), compost 3 (14.03 cm) and compost 4 (11.70 cm) (Figure 7.7)

The *Sargassum* compost significantly (P=0.01) influenced the petiole length of okra from 3 to 8 WAP in the second trial (Figure 7.7). Significant difference (P=0.01) existed among the compost from 3 to 8 WAP. Compost 2 (50:40:10) appeared best, recording the highest mean values of petiole length (13.97 cm) followed by compost 1 (13.85 cm). Significant difference (P=0.01) existed among okra varieties from 4 to 8 WAP. Okra Volta appeared best in terms of petiole length (13.60 cm) followed by Clemson spineless (11.55 cm). Regarding compost and variety interaction, no significant differences (P>0.05) existed in all the treatment means from 3 to 8 WAP. For all the treatments tested, okra Volta recorded the highest mean value of petiole length in 5 out of the 6 treatments (soil amended with inorganic fertilizer (12.92 cm), compost 1 (15.65 cm), compost 2 (16.12 cm), compost 3 (16.12 cm) and compost 4 (12.40 cm) (Figure 7.7).

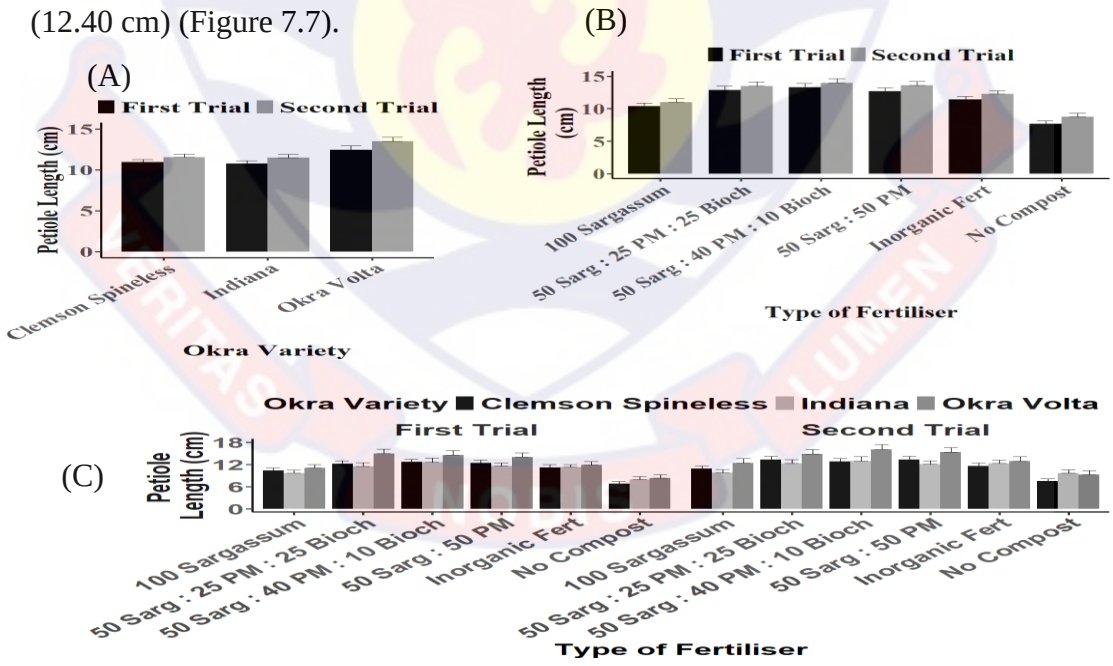


Figure 7.7: Effects of *Sargassum* compost with varying composition on petiole length of okra in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

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Effects of *Sargassum* compost on leaf area of okra (First and second trials)

The *Sargassum* compost significantly (P=0.01) affected the leaf area of okra in compost and varieties from 3 to 8 WAP in the first trial (Figure 7.8). Significant difference (P=0.01) existed among compost from 3 to 8 WAP. Compost 3 (50:50) obtained the highest leaf area mean value (430.0 cm^2) followed by compost 2 (50:40:10) (402.3 cm^2) (Figure 7.8). Significant difference (P=0.01) existed among okra varieties from 7 to 8 WAP. Okra Volta recorded the highest mean leaf area (336.5 cm^2) followed by Indiana (313.0 cm^2). No significant difference (P > 0.05) existed between the compost and variety interaction from 3 to 8 WAP. Okra Volta obtained the highest mean leaf area in 4 out of 6 treatments, control (171.5 cm^2) compost 1 (454.3 cm^2), compost 3 (442.4 cm^2) and compost 4 (179.7 cm^2) (Figure 7.8)

The *Sargassum* compost significantly (P=0.01) affected the leaf area of okra from 3 WAP to 8 WAP in the second trial (Figure 7.8). Significant differences (P=0.01) existed among compost treatments from 3 to 8 WAP. Compost 1 (50:25:25) recorded the highest mean leaf area (201.7 cm^2) followed by compost 3 (190.2 cm^2) and compost 2 (180.2 cm^2). Significant differences (P=0.01) existed among the okra varieties from 6 to 8 WAP. Okra Volta recorded the highest mean leaf area (178.3 cm^2) followed by Indiana (159.9 cm^2). There were no significant differences (P > 0.05) among compost and variety interactions from 3 to 8 WAP. However, leaf area increased from 3 to 8 WAP for all varieties. Okra Volta recorded the highest mean leaf area in compost 1 (237.3 cm^2), compost 2 (216 cm^2) and compost 3 (228.4 cm^2), while Indiana also recorded the highest mean leaf area in control (87.2 cm^2) and soil amended with inorganic fertilizer (190.2 cm^2) (Figure 7.8)

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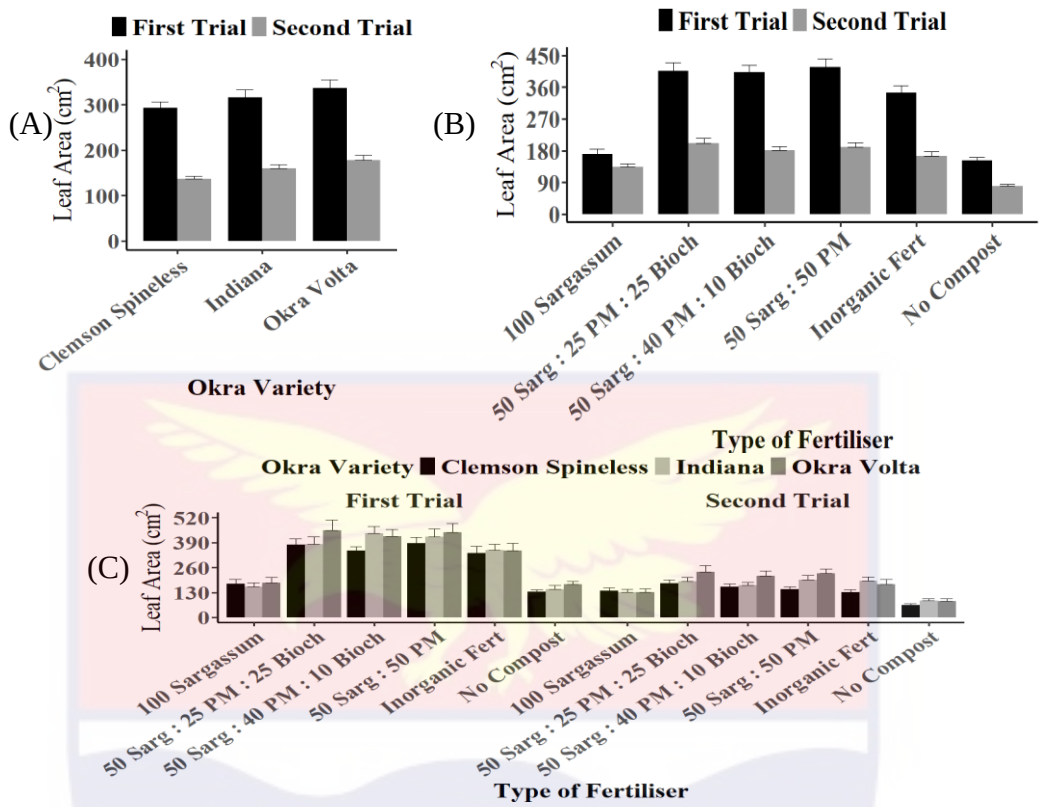


Figure 7.8: Effects of *Sargassum* compost with varying composition on leaf area of okra in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effect of *Sargassum* compost on stem girth of okra (First and second trials)

The *Sargassum* compost significantly (P=0.01) affected the stem girth of okra from 3 to 8 WAP in the first trial (Figure 7.9). Significant difference (P=0.01) existed in compost from 3 to 8 WAP. Compost 3 recorded the highest stem girth mean value (15.53 mm) followed by compost 2 (50:40:10) (15.43 mm) (Figure 7.9). There was a significant difference (P=0.05) among okra varieties in 3 WAP. Okra Volta appeared best, obtaining the highest mean stem girth (13.46 mm) followed by Clemson spineless (12.84 mm) (Figure 7.9). No significant differences (P > 0.05) existed among compost and variety interaction from 3 to 8 WAP. While okra Volta recorded the highest mean stem girth in control (8.92 mm), compost 2 (16.77 mm) and compost 3 (16.96 mm), Indiana

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recorded the highest mean stem girth in soil amended with inorganic fertilizer (14.33 mm) and compost 4 (11.82 mm) (Figure 7.9)

The *Sargassum* compost significantly (P=0.01) affected the stem girth of okra from 3 to 8 WAP in the second trial (Figure 7.9). Significant differences (P=0.01) existed among compost from 3 to 8 WAP. Compost 3 (50:50) appeared best, recording the highest mean stem girth (10.35 mm) followed by compost 2 (50:40:10) (10.29 mm) (Figure 7.9). A significant difference ($P < 0.05$) existed between okra Volta and Clemson spineless in 7 and 8 WAP. Okra Volta appeared best regarding stem girth with the highest mean value (9.35 mm) followed by Indiana (8.92 mm). With regards to compost and variety interaction, okra Volta recorded the highest mean stem girth value in compost 1 (10.60 mm), compost 2 (10.75 mm), compost 3 (11.35 mm) and compost 4 (8.85 mm) (Figure 7.9).

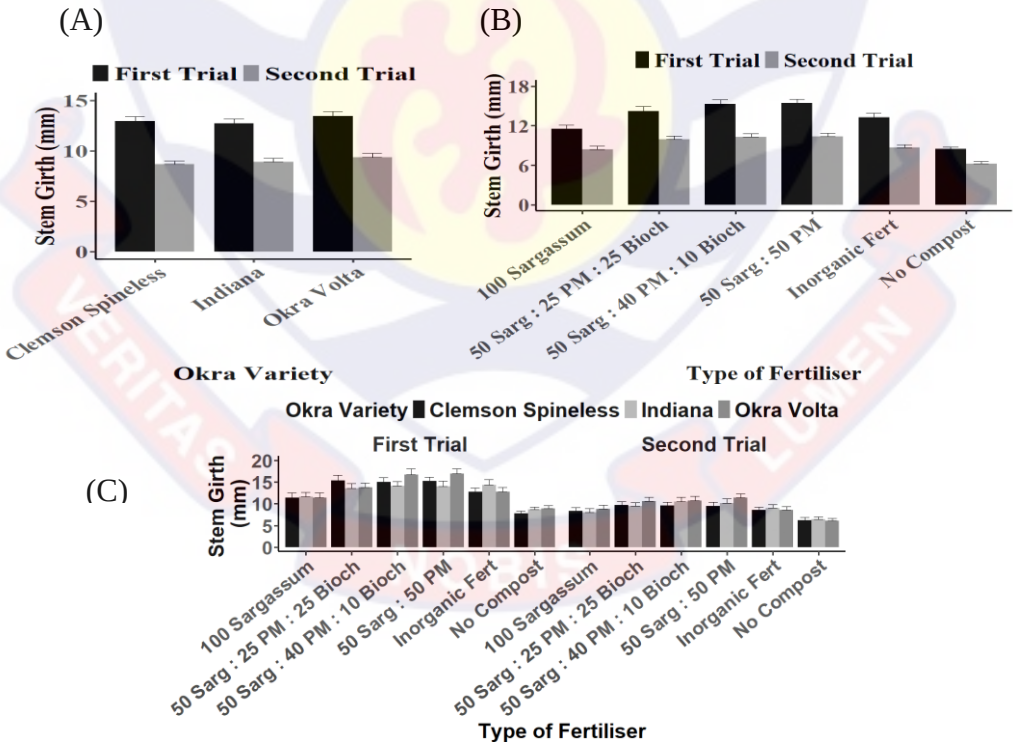


Figure 7.9: Effects of *Sargassum* compost with varying composition on stem girth of okra in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

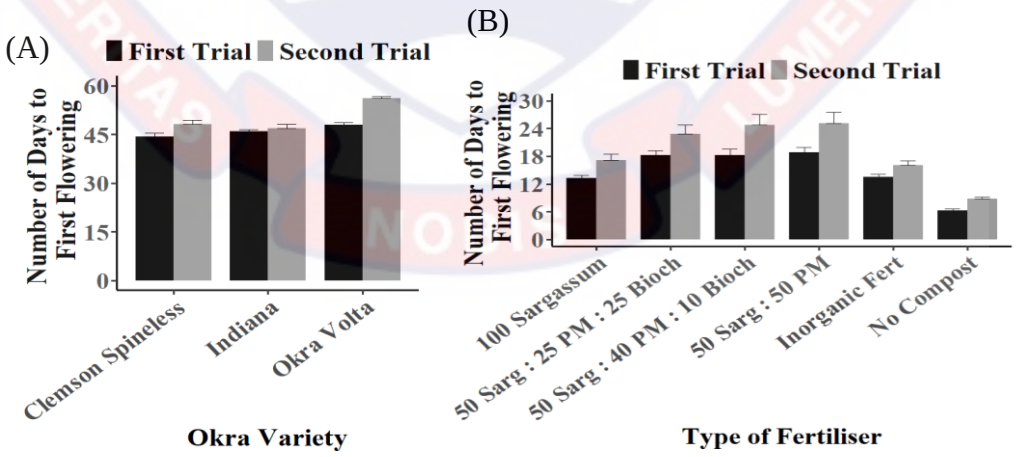
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Effects of *Sargassum* compost on days to 1st flowering of okra

Sargassum spp. compost and variety significantly (P = 0.01) influenced days to 1st flowering of okra varieties in the first trial (Figure 7.10). It took Clemson spineless 44.4 days to 1st flowering, while it took 48.0 days for 1st flower to appear in okra Volta. There were no significant differences in compost and interactions between compost and variety. Flower formation started first in compost 3 (50:50) with a mean value of 44.7 days, while compost 1 (50:25:25) recorded a late flowering of 47.9 days. Okra Volta took the longest day (49.5 days) to flower in soil amended with inorganic fertilizer. In comparison, Clemson spineless took the shortest day (42.0 days) in compost 3 to flower (Figure 7.10).

In the second trial, *Sargassum* spp. significantly (P=0.01) differed for the days to 1st flowering of okra varieties (Figure 7.10). In okra varieties, Indiana flowered 1st in 46.9 days, followed by Clemson spineless (48.1 days). No significant difference existed between compost and variety interactions. The 1st flower formation occurred in compost 2 (50:40:10), compost 3 (50:50) and compost 4 (100 *Sargassum*) in 49.0 days. Okra Volta took the longest day (57 days) to flower in compost 3. In comparison, Clemson spineless took the shortest day (44.3 days) to flower in compost 3 (Figure 7.10).



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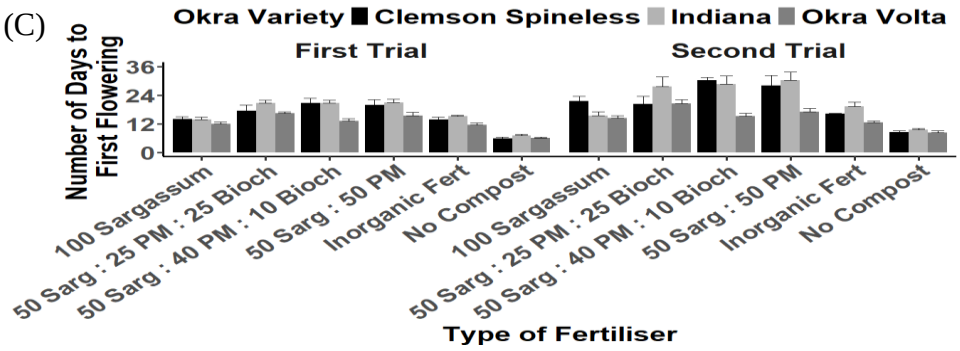


Figure 7.10: Effects of *Sargassum* compost with varying composition on the days to 1st flowering of okra in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on days to 50% flowering of okra (First and second trials)

The main and interaction effects of *Sargassum* compost and variety differed significantly (P=0.01) for days to 50% flowering of okra in the first trial (Figure 7.11). It took 43.3 days to 50% flowering in soil without compost, soil amended with inorganic fertilizer, compost two and compost 3. Clemson spineless took shorter days (40.8 days) to achieve 50% flowering, followed by Indiana (44.2 days and okra Volta (46.0 days). Regarding compost and variety interaction, Clemson spineless took the shortest days (38.0 days) to attain 50% flowering in soil amended with inorganic fertilizer, while okra Volta took the longest days (48.5 days) to attain 50% flowering in compost 1 (Figure 7.11).

In the second trial, the effects of *Sargassum* spp compost and variety as well as their interactions differed significantly (P=0.01) for days to 50% flowering of okra. (Figure 7.11). It took 46.8 days to 50% flowering in soil without compost and 50.7 days to 50% flowering in soil amended with inorganic fertilizer (Figure 7.11). In okra variety treatment, Indiana took 44.5 days to attain 50% flowering, while it took okra Volta 54.2 days to attain 50% flowering. For compost and variety interaction, it took Indiana and Clemson spineless the shortest days (41.0 days) to attain 50% flowering in compost 1

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and compost 2, whereas it took okra Volta the longest days (57.0 days) to attain 50% flowering in composts 1 and 4 (Figure 7.11).

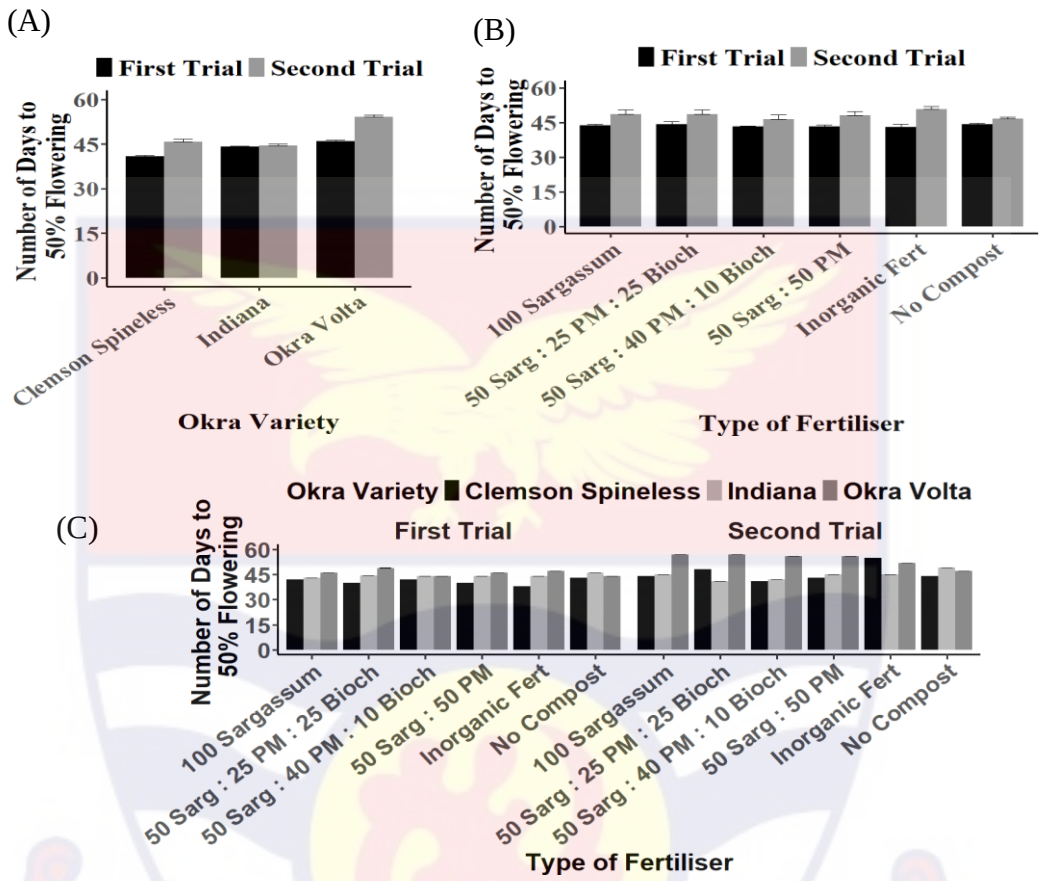


Figure 7.11: Effects of *Sargassum* compost with varying composition on the days to 50 % flowering of okra in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on the number of fruits of okra plant^{-1} (First and second trials)

The effects of *Sargassum* spp. compost and variety of okra and their interactions significantly (P=0.01) varied for the number of fruits of okra plant^{-1} in both the first and second trials (Figure 7.12). At the same time, compost 3 (50:50) recorded the highest number of fruits (18.50), and soil without compost produced the least number of okra fruits (6.0). Indiana recorded the highest fruits (15.9) while okra Volta obtained the least fruit plant^{-1} (12.0). The order of fruit number in ascending order was okra Volta<Clemson spineless<Indiana. Indiana obtained the highest number of fruits in all

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the compost treatments, except compost 2 (50:40:10) for compost and variety interaction.

For the second trial, compost 3 (50:50) had the highest number of fruits plant^{-1} (24.9), followed by compost 2 (50:40:10) (24.3). Indiana produced the most fruits plant^{-1} (21.4), while okra Volta produced the fewest fruits per plant (14.0). The order in fruit number in ascending order was okra Volta<Clemson spineless<Indiana. Indiana produced the highest number of fruits per plant across all the compost treatments in the compost x variety interaction, with the exception of compost 2 (50:40:10) (Figure 7.12).

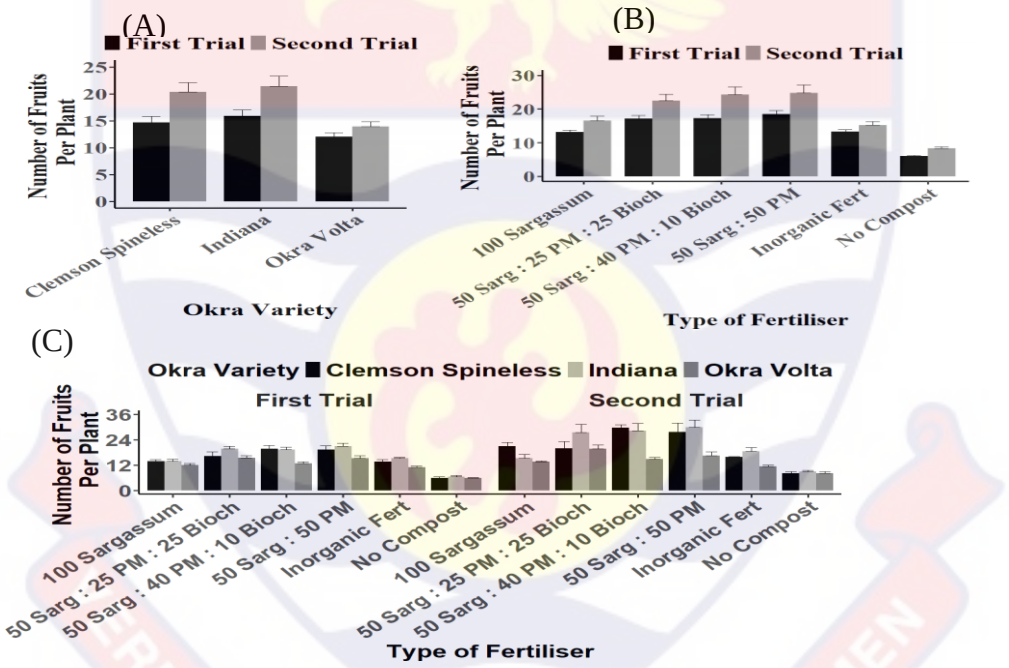


Figure 7.12: Effects of *Sargassum* compost with varying composition on the number of fruits of okra per plant in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on single fruit weight of okra plant^{-1} (First and second trials)

In the main experiment, the single fruit weight of okra per plant was significantly (P=0.01) impacted by the *Sargassum* compost (Figure 7.13). With a single fruit weight plant^{-1} of 16.8 g, compost 3 (50:50) had the best value, followed by compost 2 (50:40:10) with 14.3 g. The variety of okra, had significant (P = 0.05) effects on mean

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fruit weight. Indiana recorded the highest single fruit weight plant^{-1} (12.8 g), followed by Clemson spineless (12.4 g). There were significant differences (P=0.01 in the compost x variety interaction effects. Indiana recorded the highest single fruit weight plant^{-1} in soil amended with inorganic fertilizer (11.2 g), compost 1 (15.5 g) and compost 2 (16.0 g). The Clemson spineless variety recorded the highest single fruit weight plant^{-1} in soil without compost (7.8 g), compost 3 (20.0 g), and compost 4 (11.4 g) (Figure 7.13).

In the second trial, the effects of *Sargassum* compost significantly (P=0.01) influenced the single fruit weight of okra plant^{-1} (Figure 7.13). However, the main effects of variety of okra with its interaction with compost were not significant. Compost 3 (50:50) recorded the highest single fruit weight plant^{-1} (16.8 g), followed by compost 2 (50:40:10) (11.6 g). Clemson spineless and okra Volta recorded the highest single fruit weight plant^{-1} (10.5 g) in the okra variety, followed by Indiana (10.3 g) (Figure 7.13)

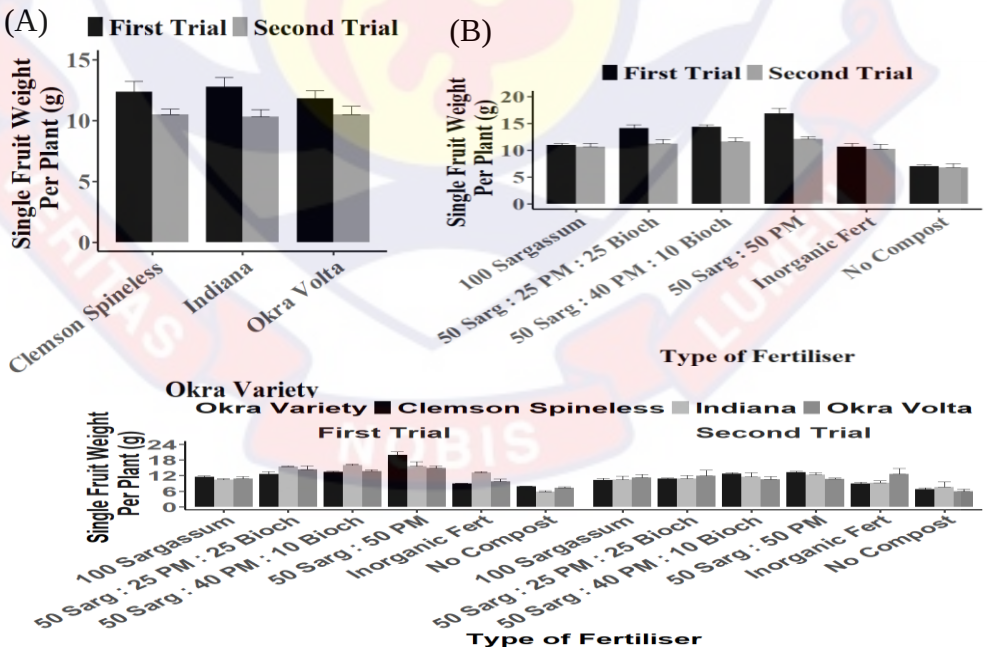


Figure 7.13: Effects of *Sargassum* compost with varying composition on single fruit weight of okra per plant in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M

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Effects of *Sargassum* compost on fruit length of okra (First and second trials)

In the first trial, the impact of *Sargassum* compost on okra fruit length was significant (P=0.01) (Figure 7.14). The highest fruit length value was recorded by compost 2 (15.3 cm) followed by compost 3 (14.8 cm). Clemson spineless appeared best, recording the highest okra length of 15.1 cm, followed by Indiana with a fruit length of 12.6 cm. There were significant differences (P=0.05) between each nutrient-applied treatment for the control in the compost and variety interaction. Clemson spineless maintained its superiority, appearing best in 5 out of 6 treatments, recording the highest fruit length value of 15.0 cm in soil amended with inorganic fertilizer, 18.0 cm in compost 1 and compost 2, 16.9 cm in compost 3 and 14.6 cm in compost 4 (Figure 7.14).

The impact of *Sargassum* compost and okra variety and their interactions on okra fruit length was significant (P=0.01) in the second trial (Figure 7.14). In the compost treatment, compost 2 (50:40:10) recorded the highest mean value of fruit length (14.0 cm), followed by compost 3 (50:50) (13.7 cm). In the okra variety treatment, Clemson spineless appeared best, recording the highest mean value of fruit length (15.1 cm), followed by Indiana (12.6 cm). In compost and variety interaction, Clemson spineless recorded the highest fruit length mean value in all the compost treatments, except the control; thus, soil amended with inorganic fertilizer recorded 15.5 cm, compost 1 (18.3 cm), compost 2 (19.3 cm), compost 3 (15.9 cm) and compost 4 (15.8 cm) (Figure 7.14).

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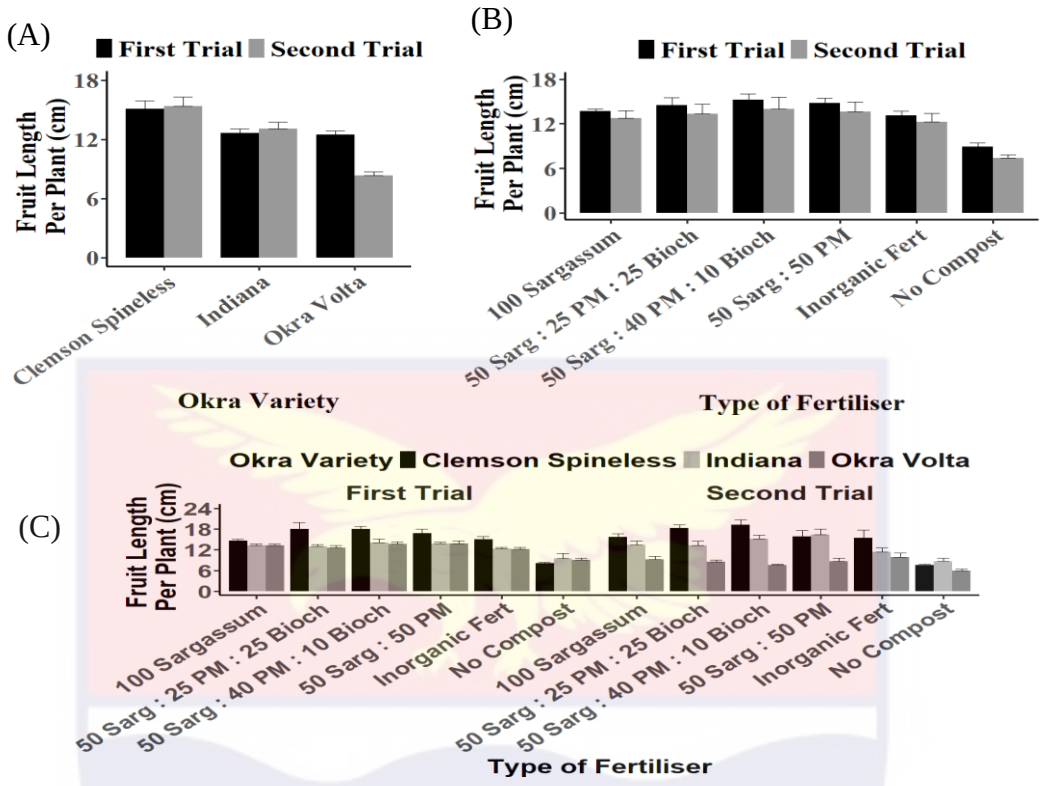


Figure 7.14: Effects of *Sargassum* compost with varying composition on fruit length of okra per plant in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on fruit diameter plant-^{1} of okra (First and second trials)

The effects of *Sargassum* compost and okra variety significantly (P=0.01) differed for the single fruit diameter of okra in the first trial (Figure 7.15). For compost, the highest fruit diameter was recorded by compost 3 (50:50) (18.31 mm), followed closely by compost 1 (50:25:25) (18.18 mm). Clemson spineless recorded the highest fruit diameter of 17.22 mm in the okra variety, followed by okra Volta (17.10 mm). There was no significant difference in the fruit diameter treatment means for the compost and variety interactions (Figure 7.15).

In the second trial, the effects of *Sargassum* spp. Compost, okra variety and the interaction between variety ans compost significantly (P=0.01) varied for single fruit diameter plant^{-1} of okra (Figure 7.15). Compost 1 (50:25:25) recorded

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the highest mean value of fruit diameter (19.07 mm), followed by compost 3 (50:50) (18.51 mm). In the okra variety, Clemson spineless recorded the highest mean value of fruit diameter (19.07 mm), followed by okra Volta (17.11 mm) (Figure 7.15). In the compost and variety interactions, Clemson spineless obtained the highest mean value of fruit diameter in soil amended with inorganic fertilizer (19.42 mm), compost 1 (21.93 mm), compost 2 (22,64 mm) and compost 3 (24.34 mm) (Figure7.15).

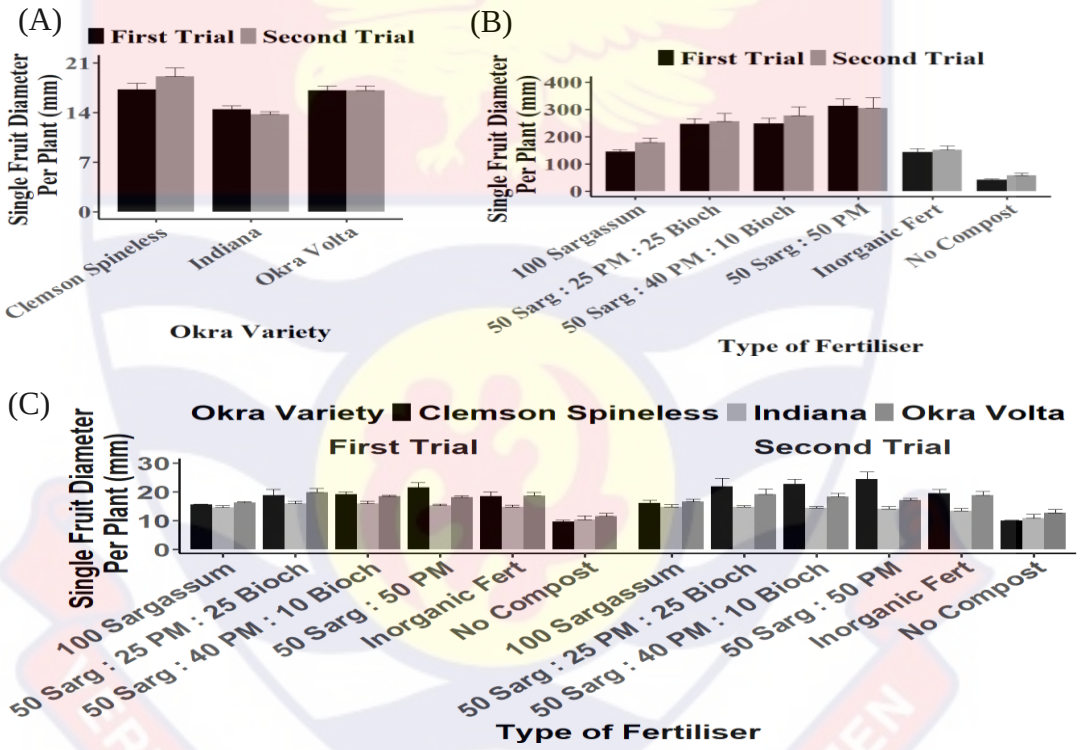


Figure 7.15: Effects of *Sargassum* compost with varying composition on fruit diameter of okra per plant in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

Effects of *Sargassum* compost on number of seeds fruit^{-1} of okra (First and second trials)

The effects of both the compost and the okra cultivars and the number of seeds fruit-^{1} were highly significant (P=0.01) in the first trial (Figure 7.16). For the types of compost, compost 3 (50:50) recorded the highest number of seeds fruit^{-1} (92.2) followed

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by compost 2 (50:40:10) (81.6). Of the okra varieties, the Volta okra had the highest number of seeds per fruit (77.2), followed by the Indiana (75.4). Treatment interaction effects on the parameter measured were comparable (Figure 7.16).

In the second trial, the number of okra seeds fruit^{-1} was significantly (P = 0.01) impacted by the *Sargassum* compost, okra variety and the interaction between these two effects (Figure 7.16). The compost 3 (50:50) recorded the highest number of seeds (77.8), followed by compost 1 (50;25:25) (74.1). The Clemson spineless okra variety recorded the highest number of seeds fruit^{-1} (75.4), followed by Indiana (69.2). For the compost and variety interactions, in three out of the six compost treatments, Clemson spineless in compost 2 had the most seeds per fruit (99.8), followed by compost 1 (93.2) and compost 4 (79.0). Conversely, Indiana had the most seeds fruit^{-1} in soil without compost (45.2) and compost 3 (99.0). Additionally, in soil that had been supplemented with inorganic fertilizer, okra Volta recorded the greatest number of seeds fruit^{-1} (63.5) (Figure 7.16).

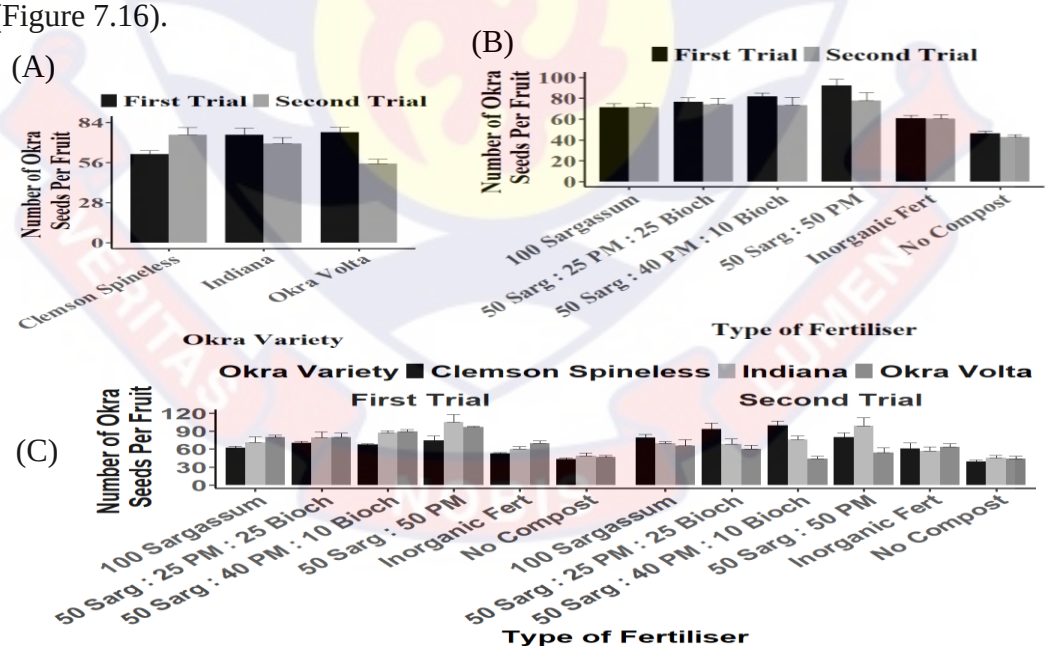


Figure 7.16: Effects of *Sargassum* compost with varying composition on number of seeds of okra per fruit in pot studies A & B (Main effects) and C (Interactive effects) for the first and second trials. Data represent the mean of four replicates with error bars representing the S.E.M.

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Discussion

Germination percentage in the first and second trials

The high porosity, aeration, water-holding capacity and the availability of humic-like compounds and other plant-growth hormones in compost-amended soils may be the cause of the observed 100% germination with higher values of germination indices (Arancon *et al.*, 2004).

Analyzing the compost's stability and maturity is essential before applying it to soil or any agricultural use. Phytotoxicity determination is critical to check compost maturity (Ravindron *et al*., 2017). Compost is matured with a germination index above 80% (Li *et al*., 2020). The matured compost makes humic substances available, making the cell more permeable to take up nutrients (Khan *et al.*, 2022) and enhancing plant growth (Maunuksela *et al*., 2021).

Plant growth parameters in the first and second trials

When added and allowed to decompose, manure or compost raises macro and micronutrients and improves the physico-chemical qualities of the soil, which promote the okra plant's strong vegetative development. The assertion made by Roesmakam & Yuwono (2002) that organic fertilizer will release micronutrients, including nitrogen, phosphorus, potassium, calcium, magnesium and sulphur for plants lends credence to this. In okra production, the current study supports the findings of Ajari *et al.* (2003), who reported that, in comparison to other forms of manure, organic manure could increase crop plant heights. In contrast to the results of this study, Tivelli *et al.* (2013) reported a mean height of 160.9 cm in okra plants when intercropped with small size leguminous species, as against the highest mean height (55 and 64 cm, respectively) obtained in compost 2 (50:40:20) in 8 WAP.

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The impact of compost in improving soil nitrogen, phosphorus, potassium, and other vital elements could be responsible for the highly significant increase in the number of leaves on the okra plants in the *Sargassum* compost. This would have boosted the plant's growth and development during the trials. According to reports, poultry manure had a relatively high nitrogen content, which promoted the vegetative growth of crops (Akanbi *et al.*, 2005). According to Dademal *et al.* (2004), it had been demonstrated that the N concentration of both organic manures increased the formation of seeds, roots and leaves.

From 3 to 8 WAP, the internode length rose gradually. Given that okra height is genetically controlled, genetic features may also be responsible for the notable increase in internode length that is proportionate to plant height (Amanullah *et al.*, 2010). Gruhn *et al*. (2000) reported that adding compost to soil had many advantages, one of which is the increase in soil aggregate stability due to humus.

The petiole length increased steadily from 3 to 8 WAP. The increase in petiole length will hold the leaf appropriately, enabling it to intercept sunlight for photosynthesis, which could have led to the growth and development of the okra plants. The increase in the petiole length could be attributed to nitrogen availability provided by the compost used, and the moisture and nutrients absorbed from the soil increased auxin supply, resulting in the creation of a nutrient-conductive root zone and encouraging physiological activity (Sarchan *et al.*, 2017).

Leaf area per plant is an important physiological trait that influences the agronomical performance of the plant. Okra cultivars with broader leaves are a desirable agronomic trait, which shows the plant’s capability to intercept more sunlight required for efficient photosynthetic activities (Joshi *et al*., 2021; Dimkpa *et al*., 2019; Oworu *et al*., 2010). The results of Ibrahim & Hamma (2012) who reported that organic manure

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may improve crop branches, plant height and leaf area of okra was supported by the current study. Nevertheless, there was no discernible interaction between variety and compost for this parameter. This may be the consequence of the okra cultivars absorbing enough nutrients in similar amounts from the compost. The plant with the largest leaf area was okra Volta. This study supports the findings of Bandyopadhyay *et al.* (2001), who reported that, okra cv *Parbhani Kranti* plants had the largest leaf area and growth rate.

In the current study, the stem girth of plants increased from 3 to 8 WAP. All of the compost, with the exception of compost 4 (100 *Sargassum*), performed better than the soil amended with inorganic fertilizer in this study. The notable increase in growth may have been caused by improved pH, electrical conductivity and soil fertility, as reported in literature (Lehmann *et al.*, 2003; Liang *et al.*, 2006; Solomon *et al.*, 2007). Decomposed elements from the biological breakdown of organic matter under aerobic conditions may be the cause of this (Storey, 1995; Epstein, 1997). Bigger stem diameters of okra may confer high resistance to strong winds and other climatic factors, which may cause logging, confirming other researchers reports (Joshi *et al*., 2021; Mehta *et al*., 2017; Okoli, 2021).

Phenological and yield parameters of okra in the first and second trials

There was variation in the flowering of okra varieties in this study. These okra cultivars' varying flowering times may have resulted from their innate genetic differences regarding photoperiodism. This study agrees with Singh *et al.* (1996) who noted that the length of time needed for *Arka Anamika* to flower for the first time varied among okra cultivars. However, in the present study, there was delayed flowering in compost 1 (50:25:25), soil amended with inorganic fertilizer and the control in both trials. This may be related to the increased nitrogen treatment since higher nitrogen

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doses eventually resulted in lush growth during the vegetative phase, which postponed flowering. The results of Jose (1988) and Nandhakumar (1997) supported the findings of this study. While 50% flowering was achieved first in soil amended with inorganic fertilizer in the first trial, compost 2 (50:40:10) recorded 50% flowering in the shortest possible duration in the second trial. The varying growth conditions in the modified soil medium may have been the cause of the variances in flowering. The variation in flowering might be due to seasonal variations such as temperature, day length and humidity. Rajesh *et al.* (2018) reported similar results, indicating that the early flowering genotypes could be useful for multiple year-round production, thereby ensuring sustainable okra production and improving farmers' livelihood.

Compost 3 (50:50) recorded the highest fruits in both experiments. The larger size of plant canopy and increased number of fruit branches brought about by fertilizer administration could have contributed to the higher number of fruits/pods obtained in this study. The findings of Shridhar (1996) who stated that a certain okra variety produced a maximum number of fruits (12.0) are not consistent with the results of this study. Meanwhile, Singh *et al.* (1996) reported similar results in line with the current study. This study yielded a lower mean number of fruits than Oliveira *et al*. (2007, 2014), who reported 43 and 26 fruits plant^{-1}, respectively. Premsekhar & Rajasree (2009) reported that a higher proportion of productive flowers could be the cause of the higher fruit set. The current study revealed that the effect of *Sargassum* compost significantly increased single fruit weight plant^{-1} in all the treatments than the control. The plants may have received extra assistance from the soil in manured pots due to its enhanced capacity to store water and its increased nutrients availability (Agarwala *et al.*, 1981; Tisdale & Nelson, 1978). Furthermore, compared to inorganic fertilizer alone and the control, there was an increase in the amount of organic matter in the soil

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by the addition of compost to the soil and this enhanced its physical and chemical qualities (Ofosu-Anim *et al*., 2006). The present study's outcome is consistent with the research conducted by Sanwal *et al.* (2007) on turmeric (*Curcuma longa*) and Premsekhar & Rajashree (2009) on okra. Since the Indiana okra variety recorded the highest single fruit weight plant^{-1}, the okra variety can be suggested for multi-location evaluation to facilitate their considerations for official release as cultivars and the wider coverage of farmers' adoption of open field okra cultivation of Ghana. Given that these treatments contain organic fertilizers, it is possible that the increased fruit weight is the result of photosynthetic activity moving more quickly from the source to the sink under the effect of growth hormone (Susan, 1995). This validates the finding of Mal *et al*. (2014). The noteworthy extension of fruit length may be ascribed to the ample nutrients provided by compost, which foster the development of advantageous soil microorganisms that enhance soil health (Neeson, 2004). It could also mean that the nutrients produced were not diverted to the plant's vegetative growth alone, but also to fruit formation and its elongation. The longest fruits were registered by Clemson spineless (15.4 cm), and the shortest fruits were recorded by okra Volta (8.3 cm) validate the results of Mishra *et al*. (2001) who found that switching cultivars led to an increase in okra pod length. The more fruits the okra variety produced, the more photosynthates could have been allocated to increase their fruit sizes. Moreover, the process of composting plant leftovers releases a significant amount of organic matter and nutrients into the soil (Yih-Chi *et al*., 2009). The uptake of Mg boosts photosynthesis in plants. However, besides the high local demand, farmers can consider the export market for consumption or processing. Due to this, okra fruit quality attributes are very important when selecting a cultivar for cultivation (Alam *et al*., 2021). For instance, according to the okra export guide to the USA (IICA, 2006),

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the minimum standard for fruit diameter was half an inch (12.7 mm) (Oliveira *et al*., 2014). As a result, all three okra varieties in this study are desirable for export, particularly into the USA export market. Gibberellic acid (GA) applied foliarly had been shown to influence the quantity of seeds and fruit (Marie *et al.,* 2007; Hoque & Haque, 2002). The compost-amended soil recorded a greater number of seeds than the soil amended with inorganic fertilizer and the control probably because the compost had quality organic matter, which decomposed gradually to release mineral elements, especially potassium, slowly for the plant's uptake until the reproduction phase of its development to initiate high seed production. Compost 3 (50:50) recorded the highest number of seeds in both experiments, perhaps due to its high poultry manure content in the compost (Ofosu-Anim *et al*., 2006). Okra Volta obtained the highest number of seeds in the first trial and maintained its superiority over other varieties in 4 out of the six treatments regarding the highest number of seeds in the compost and variety interaction. The okra genotypes' innate genetic diversity may be the cause of this variance in seed quantity.

Conclusion

Growth parameters

Compost 3 (50:50) recorded the highest seed germination percentage. Except for compost 4 (100 *Sargassum*), the other three composts recorded taller plant height and more leaves than the control and soil that had been supplemented with inorganic fertilizer treatment. Additionally, all four *Sargassum* composts recorded higher internode and petiole length than soil amended with inorganic fertilizer and the control. Except for compost 4, all three other composts outperformed inorganic fertilized and control in leaf area per plant and plant stem girth. Indiana recorded the highest seed germination percentage than Clemson spineless and okra Volta. The okra Volta had

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the highest plant height, and more plant leaves, longest internodes and longer petioles. Additionally, okra Volta recorded broader leaves (leaf area) and plant stem girth than the other varieties at 7 and 8 WAP.

Yield parameters

Compost 3 (50:50) took the shorter number of days to flower. Regarding days to 50% flowering, soil amended with inorganic fertilizer took the shortest days to 50% flowering in the first trial, and compost 2 (50:40:10) achieved the same feat in the second trial. Furthermore, in both trials, compost 3 (50:50) produced the highest number of fruits per plant. Furthermore, regarding single fruit weight plant^{-1} and fruit length, all the composts performed better than inorganic fertilizer and control treatments. Regarding single fruit diameter, all the compost, except compost 4, recorded a higher fruit diameter than soil amended with inorganic fertilizer. Once more, all of the composts outperformed the soil treated with inorganic fertilizer and the control, yielding the greatest number of seeds. Clemson spineless took the shortest number of days to flower in the first trial, and Indiana took the shortest number of days to flower in the second trial. Clemson spineless took the shortest days to 50% flowering during the first trial, while Indiana achieved the same feat in the second trial. In both trials, Indiana recorded the highest number of fruits per plant while okra Volta recorded the lowest number of fruits per plant. Indiana performed better by recording the highest single fruit weight in the first trial. However, it has the lowest fruit weight in the second trial. Clemson spineless recorded the highest fruit length and obtained the highest fruit diameter than the other okra varieties. While okra Volta produced the highest number of seeds per fruit in the first trial, Clemson spineless recorded the highest number of seeds per fruit in the second trial.

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CHAPTER EIGHT

INFLUENCE OF SARGASSUM COMPOST ON CHEMICAL PROPERTIES OF A HAPLIC ACRISOL SOIL CROPPED TO OKRA

Introduction

Crop maturity within designated growing seasons is ensured by effective fertilizer application (Okalebo, 1987). Thus, fertilizer effectiveness depends on a variety of factors, including their chemical and physical characteristics, rate and mode of fertilizer application, soil and climate and crop species (Mokwunye & Bationo, 2002). High-mineral fertilizers have been used more frequently in recent years because of financial concerns. Some examples of inorganic fertilizers that are used are triple super phosphate (TSP), 50% urea and diammonium phosphate (DAP), according to Smalling *et al.* (1997).

Compost contains essential plant nutrients and other trace elements, including nitrogen, phosphorus, potassium, calcium, magnesium and sulphur (Agegnehu *et al.*, 2014; Madeleine *et al*., 2005). Compost is a multi-nutrient organic fertilizer, according to Amlinger *et al.* (2007). According to Tisdale & Nelson (1990), nitrogen is the most crucial nutrient for plant growth and is absorbed by many plants as nitrate. Most plants contain between 1.7% and 5.8% of nitrogen by dry weight, which is necessary for the synthesis of chlorophyll, photosynthesis and carbon dioxide (CO_2) absorption (Jasso-Chaverria *et al*., 2005). Nitrogen and other minerals like phosphorus, potassium and calcium work synergistically and plants that lack nitrogen in the soil will also lack other nutrients (Brady, 1984). Chlorosis, brought on by insufficient nitrogen, causes leaves to turn yellowish-green, slows down growth, and may even cause lower leaves to die (Martin *et al.*, 2006; Silas *et al.*, 2012).

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One of the elements of plants' intricate nucleic acid structure, phosphorus (P), controls the synthesis of proteins. A lack of P causes the plant to seem spindly or stunted, grow slowly, have purple petioles, have poor root development and produce fewer fruits (Martin *et al*., 2015; Martin *et al*., 2006; Silas *et al*., 2012).

Moreover, plants need potassium (K) ions for protein functions, particularly the upkeep of positive ion balance and the satisfaction of negative ion charges on proteins. K is also necessary for synthesizing high-energy molecules, osmotic regulation, stoma opening regulation and enzyme activation. Potassium shortage causes shorter internodes, plant dwarfism, loss of green colour, marginal discoloration, early leaf death, smaller fruits and white patches on leaves (Martin *et al.*, 2006).

The literature's reported beneficial effects of compost on crop productivity and soil quality (Hoitink *et al.*, 1997; Atiyeh *et al.*, 2001) are strongly correlated with the physical, chemical and biological properties of the composts (He *et al.*, 1995). Although researchers examined the physical characteristics of soils, including bulk density, moisture content, moisture holding capacity and porosity, little is known about the post-harvest okra soil's chemical characteristics, including pH, EC, total organic carbon, electrical conductivity, total nitrogen, available phosphorus, exchangeable potassium, sodium, calcium, magnesium and effective cation exchange capacity. As a result, this chapter emphasised how *Sargassum* spp. compost affected a few specific chemical characteristics of post-harvest soil grown to okra.

Objective

To evaluate the impact of *Sargassum* compost on the chemical properties of soil cultivated with okra.

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Hypothesis

Ho: The post-harvest chemical properties of the soil cultivated with okra and amended with *Sargassum* compost are the same as those of unamended soil.

Hi: The post-harvest chemical properties of the soil cultivated with okra and amended with *Sargassum* compost differ from those of unamended soil.

Materials and methods

Post-harvest activities on media preparation grown to okra

At the end of harvesting okra, the post-harvest soils of each treatment were sampled from the root zone of each plant and put in a labelled zip lock polythene rubber for air-drying in the laboratory. Each pot's air-dried soil was carefully mixed and after that, slightly crushed to pass through a 2 mm sieve before being transported to the UCC Soil Science Laboratory for chemical analysis. The pH, total organic C, total N, extractable P, and exchangeable bases (Ca^{2+}, Mg^{2+}, and K^{+}) of the <2-mm samples were then analyzed using the procedure outlined by Rowell (1994). Anderson & Ingram's (1993) method was used to determined exchangeable acidity ($Al^{3+}H^{+}$). The soil-to-soil-to-water ratio of 1:2.5 was used to measure the pH and the total organic carbon was determined using the method of wet oxidation as described by Walkley & Black (1934). Through acid digestion, nitrogen was assessed and the total nitrogen was quantified using the micro-Kjeldahl method. Bray No. 1 extract was used to calculate extractable P and the spectrophotometer was used to read the sample at 882 nm.

Statistical analysis

To ascertain the significance of the data, general analysis of variance (ANOVA) was carried out using GenStat Twelfth Edition, Procedure Library Release PL20.I, 2009 (VSN International Limited, Rothamsted Experimental Station, Hemel Hempstead, UK). Fisher's protected Least Significant Difference test with 5% probability and

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Tukey's Honestly Significance Different (HSD) were used to separate the means. The data were represented graphically using R statistical sofware.

$$Y_{ijk} = \mu + v_i + c_j + r_k + vc_{ij} + \varepsilon_{ijk} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [8.1]$$

Where Y_{ijk} = observation from the ijk^{th} okra variety, compost and replication, μ = overall mean, v_i = effect of the i^{th} okra variety, c_j = effect of the j^{th} compost, r_k = effect of the k^{th} replication, vc_{ij} = interactive effect of the i^{th} okra variety with the j^{th} compost, and ε_{ijk} = experimental error.

Results

Effects of *Sargassum* composts on pH of post-harvest soil

In the first trial, the pH of the post-harvest soil was highly significantly (P = 0.01) impacted by the application of compost made of *Sargassum* (Figure 8.1). Compost 1 (50:25:25) recorded the highest pH value (7.9 units) with the lowest pH being recorded by compost 2 (50:40:10) (7.2). The pH levels of Compost 1, compost 2, composts 3 and 4 increased by 1.3, 0.6, 1.0 and 1.0 units, respectively. For the variety of okra, okra Volta recorded the highest pH (7.4), followed by Indiana (7.2). With regards to the interactions effect between compost and okra varieties, Clemson spineless recorded the highest pH value in inorganic amended soil (6.2), compost 1 (8.1), compost 3 (7.8) and compost 4 (7.9) (Figure 8.1).

The application of compost made from *Sargassum* had a significant (P = 0.01) variation on the pH of the post-harvest soil in the second trial. The effect of variety and its interactions with compost on soil pH were also significant (P = 0.01). The highest pH value was obtained by compost 2 (50:40:10) (8.0) followed by compost 3 (50:50) (7.7). The pH levels of composts 1, 2, 3 and 4 increased by 1.4, 1.8, 1.5, and 1.4 units, respectively. Regarding okra varieties, Indiana obtained the highest pH (7.6), followed by Clemson spineless (7.3). Regarding compost and variety interactions, in the control

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and compost 4, Clemson spineless obtained the highest pH value of 6.4 and 7.9, respectively. Additionally, Indiana obtained the highest pH in soil amended with inorganic fertilizer (7.8), compost 1 (8.3) and compost 3 (50:50) (7.8) (Figure 8.1).

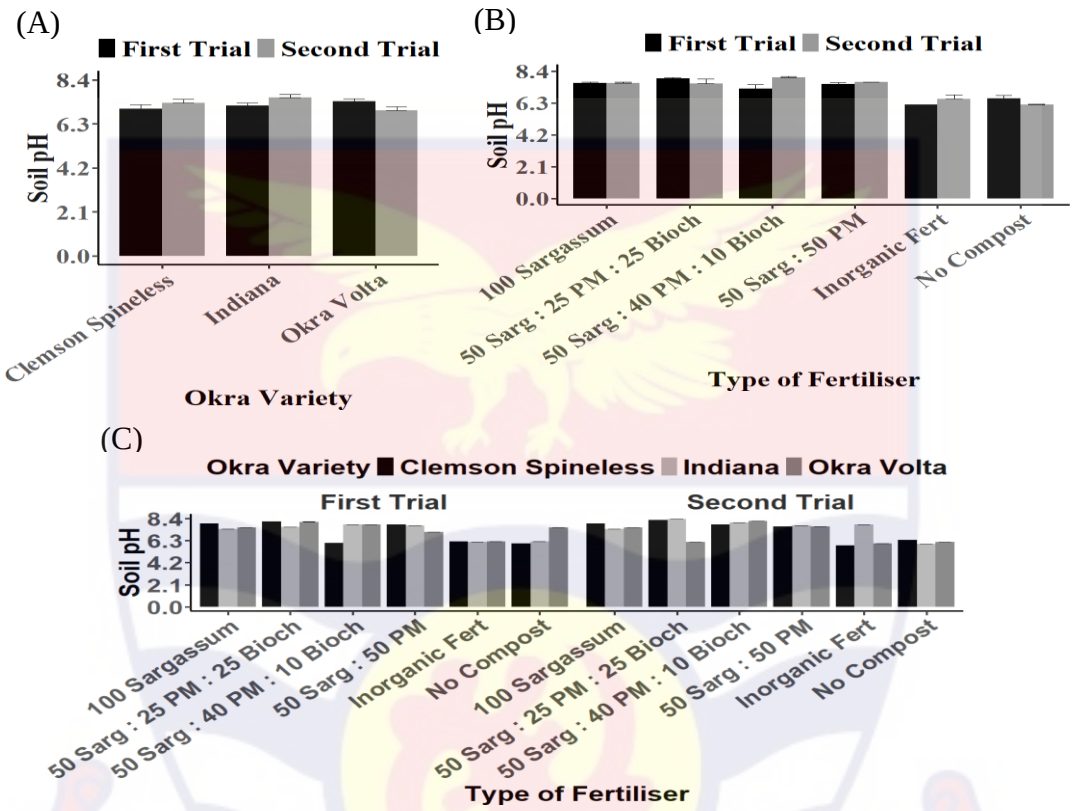


Figure 8.1: Effects of *Sargassum* compost on pH of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the mean (S.E.M).

Effects of *Sargassum* compost on post-harvest soil electrical conductivity (EC)

The *Sargassum* spp. compost application, variety of okra and the interaction between compost and variety significantly (P=0.01) influenced the electrical conductivity of post-harvest soil in both the first and second trials (Figure 8.1). In the first trial, compost 4 (100 Sargassum) recorded the highest EC value (218 μScm^{-1}), followed by compost 1 (50:25:25) (201 μScm^{-1}). Okra Volta recorded the highest EC value (163.48 µS/cm), followed by Clemson spineless (142.30 μScm^{-1}). While okra Volta obtained the highest EC values in unamended soil (113.54 μScm^{-1}), inorganic amended soil (51.25 μScm^{-1}), compost 2 (137.11 μScm^{-1}) and compost 4

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(262.54 µScm^{-1}), Clemson spineless also recorded the highest EC values in compost 3 (207.80 µScm^{-1}). Indiana in soil amended with inorganic fertilizer however, recorded the lowest EC value (41.14 µScm^{-1} (Figure 8.2).

In the second trial, the highest EC was recorded by compost 2 (50:40:10) (502.14µScm^{-1}), followed by compost 3 (50:50) (242.94 µScm^{-1}) (Figure 8.2). Regarding the okra varieties, Clemson spineless recorded the highest EC value (343.92 µScm^{-1}), followed by Indiana (218.17 µScm^{-1}). In terms of treatment interaction, Clemson spineless obtained the highest EC value in unamended soil (124.32 µScm^{-1}), soil amended with inorganic fertilizer (243.27 µScm^{-1}), compost 1 (314.21 µScm^{-1}) and compost 2 (914.33 µScm^{-1}) (Figure 8.2).

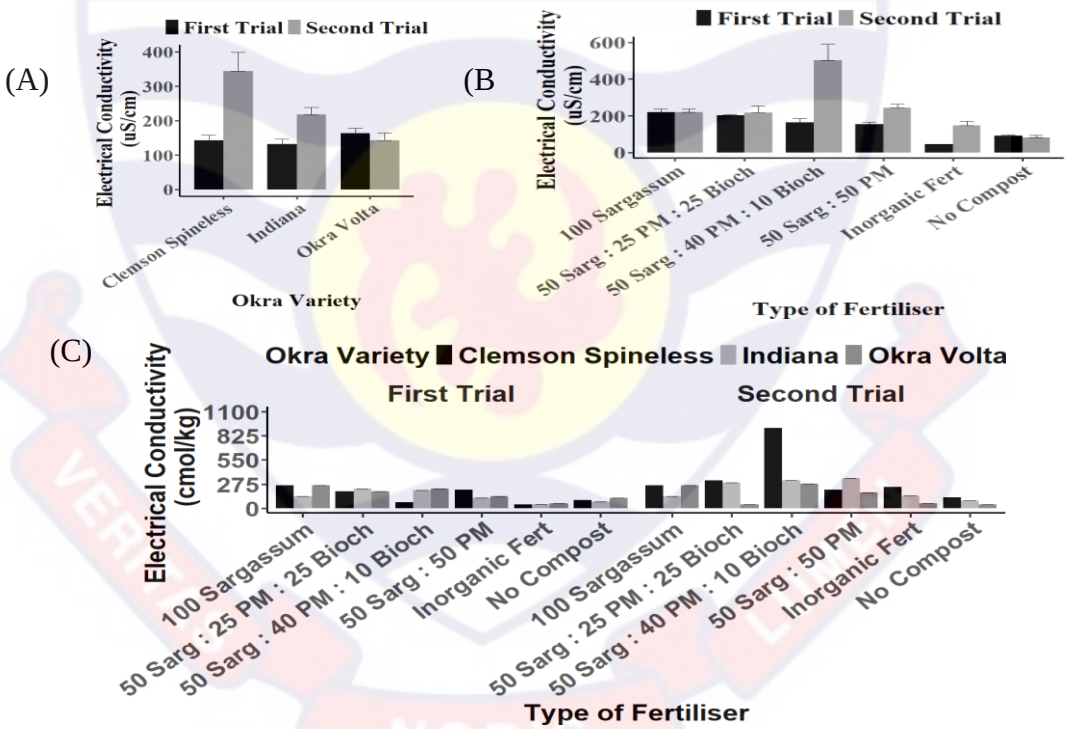


Figure 8.2: Effects of *Sargassum* compost on electrical conductivity of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

Effects of *Sargassum* compost on post-harvest soil organic carbon (OC)

The *Sargassum* compost application, okra variety and the interaction between these factors significantly (P=0.01) affected the organic carbon of the post-harvest soil

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in both the first and second trials (Figure 8.3). In the first trial, the unamended soil recorded the highest OC (0.983%), followed by compost 3 (50:50) (0.963%). Regarding the okra varieties, Clemson spineless recorded the highest OC value (0.963%), followed closely by Indiana (0.918%). With regards to compost and variety interaction, okra Volta recorded the highest OC in unamended soil (1.045%), soil amended with inorganic fertilizer (0.828%) and compost 2 (0.993%), while Clemson spineless obtained the highest OC in compost 1 (1.064%) and compost 3 (1.052%) (Figure 8.3).

In the second trial, the highest organic carbon was recorded by compost 2 (1.053%), followed by compost 3 (1.003%). Concerning okra varieties, the highest OC value was obtained by Clemson spineless (0.941%), followed by okra Volta (0.855%). With regards to compost and variety interactions, Clemson spineless obtained the highest OC value in the unamended soil (0.968%), inorganic fertilizer amended soil (0.744%) and compost 1 (0.931%), while okra Volta obtained the highest OC value in compost 2 (1.257%) and compost 3 (1.051%). However, okra Volta recorded the lowest organic carbon (0.661 %) in the control (Figure 8.3)

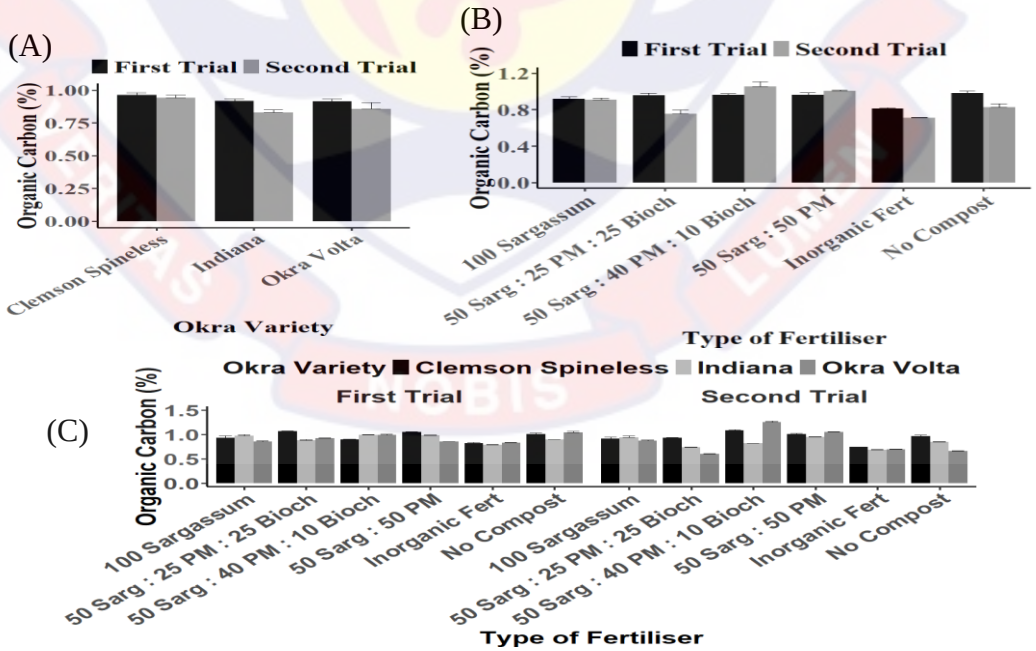


Figure 8.3: Effects of *Sargassum* compost on organic carbon of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

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Effects of *Sargassum* compost on post-harvest soil total nitrogen (TN)

The effects of *Sargassum* spp. compost application, variety of okra and their interaction had significant (P = 0.01) effects on the total nitrogen (TN) of the post-harvest soil in both the first and second trials (Figure 8.4). In the first trial, the highest TN was obtained by compost 3 (50:50) (0.963%) followed by compost 2 (0.960%). Regarding okra varieties, the highest TN value was recorded by Indiana (0.098%), followed by okra Volta (0.094%) and the lowest TN was recorded by Clemson spineless (0.086 %). With regards to the interaction effect, Clemson spineless obtained the highest TN value in compost 1 (0.091%) and in compost 4 (0.107%) while Indiana recorded the highest TN value in soil amended with inorganic fertilizer (0.055%), compost 2 (0.142%) and compost 3 (0.093%). However, the lowest TN was registered by Clemson spineless in compost 2 (0.068 %) (Figure 8.4)

In the second trial, the highest TN value was produced by compost 3 (50:50) (0.123 %), followed by compost 4 (0.103%). Regarding okra varieties, the highest TN was obtained by Clemson spineless (0.103%) followed by okra Volta (0.093%). With regards to compost and variety interaction, Clemson spineless maintained its superiority by recording the highest TN in 5 out of 6 soil amendments thus, unamended soil (0.116%), soil amended with inorganic fertilizer (0.085%), compost 1(0.094%), compost 2 (0.106%) and compost 4 (0.106%) (Figure 8.4).

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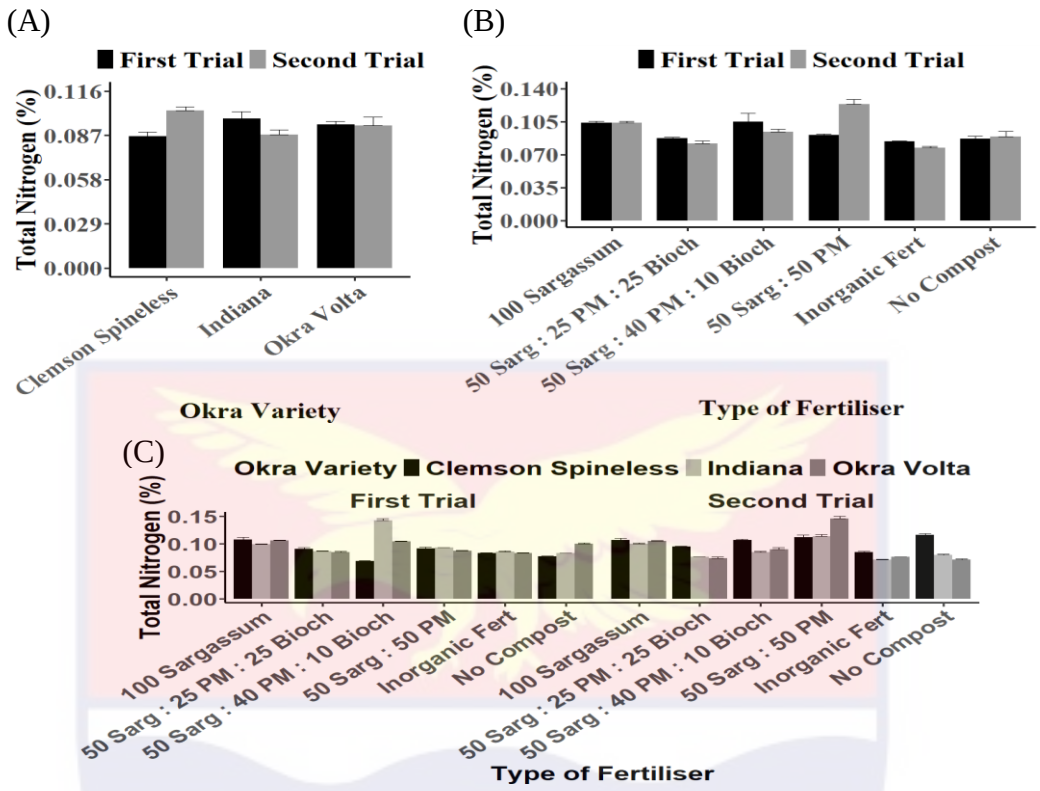


Figure 8.4: Effects of *Sargassum* compost on total nitrogen of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

Effects of *Sargassum* compost on post-harvest soil available phosphorus (P)

In both the first and second experiments, the application of compost made of *Sargassum* varieties of okra and their interactions had a significant (P = 0.01) impact on the post-harvest soil's available phosphorus (P) (Figure 8.5). In the first experiment, the highest available P value was recorded by compost 3 (50:50) (40.72 $mgkg^{-1}$), followed by compost 2 (50:40:10) (36.35$mgkg^{-1}$). Regarding okra varieties, Clemson spineless recorded the highest available P (28.99 mg kg^{-1}), followed by okra Volta (25.56 mg kg^{-1}). With regards to compost and variety interaction, Clemson spineless obtained the highest available P in compost 1 (31.63 μgg^{-1}), compost 3 (55.85 mg kg^{-1}) and compost 4 (77.06 μgg^{-1}) while Indiana, on the other hand, recorded the highest available P value in soil amended with inorganic fertilizer (4.00 mg kg^{-1}) and compost 2 (53.39 mg kg^{-1}) (Figure 8.5).

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In the second experiment, the highest available P was obtained by compost 3 (88.83 mg kg^{-1}), followed by compost 2 (88.82 mg kg^{-1}). Regarding okra varieties, Clemson spineless recorded the highest available P (54.74 mg kg^{-1}), followed by Indiana (38.78 mg kg^{-1}). With regards to compost and variety interactions, Clemson spineless obtained the highest available P in unamended soil (3.78 mg kg^{-1}), compost 1 (66.01 mg kg^{-1}), compost 3 (91.63 mg kg^{-1}), and compost 4 (77.11 mg kg^{-1}), while Indiana again obtained the highest available P in soil amended with inorganic fertilizer (2.19 mg kg^{-1}) and compost 2 (88.85 mg kg^{-1}) (Figure 8.5).

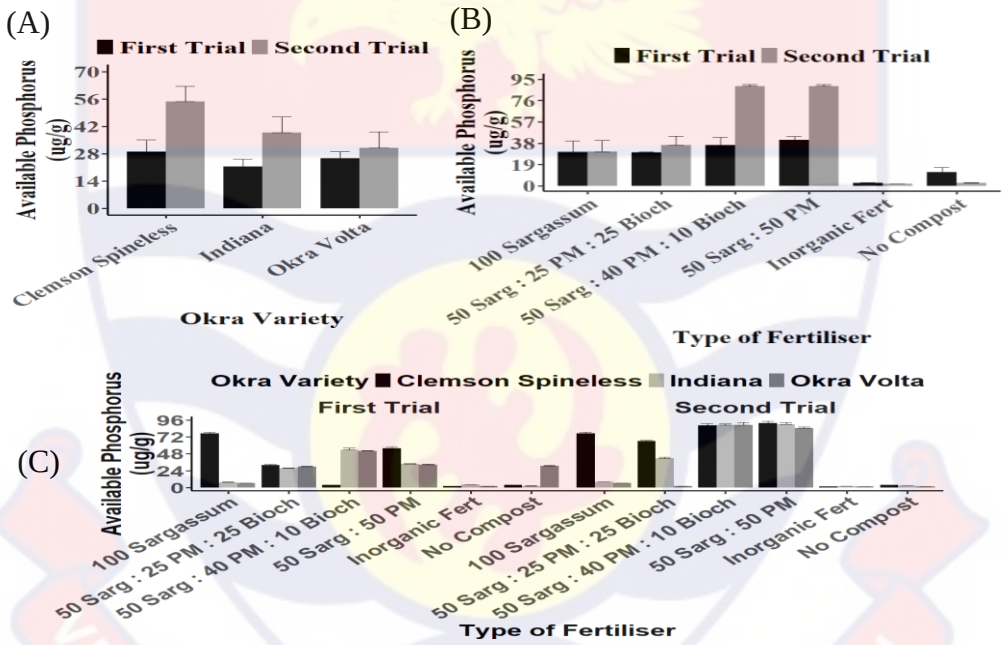


Figure 8.5: Effects of *Sargassum* compost on available phosphorus of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

Effects of *Sargassum* compost on post-harvest soil exchangeable potassium ion (K^+)

The effects of *Sargassum* compost application, varieties of okra and their interaction were significant (P=0.01) on the exchangeable potassium ion (K^+) of the post-harvest soil in both trials (Figure 8.6). In the first trial, compost 4 obtained the highest exchangeable K^+ (0.457 $cmolkg^{-1}$), followed by compost 1 (0.401 $cmolkg^{-1}$).

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Considering okra varieties, okra Volta obtained the highest exchangeable K^+ value (0.365 cmolkg^{-1}), followed by Indiana (0.313 cmolkg^{-1}). Regarding compost and variety interaction, okra Volta obtained the highest exchangeable K in 4 out of 6 soil amendment treatments. This included control (0.297 cmolkg^{-1}), soil amended with inorganic fertilizer (0.243 cmolkg^{-1}), compost 1 (0.457 cmolkg^{-1}) and compost 2 (0.514 cmol/kg). While Indiana recorded the highest exchangeable K^+ in compost 3 (0.312 cmolkg^{-1}), Clemson spineless on the other hand, recorded the highest exchangeable K^+ in compost 4 (0.588 cmolkg^{-1}) (Figure 8.6).

In the second trial, compost 2 (50:40:10) obtained the highest exchangeable K^+ (0.695 cmolkg^{-1}), followed by compost 3 (50:50) (0.482 cmolkg^{-1}) (Figure 8.6). With regards to okra varieties, Clemson spineless recorded the highest exchangeable K^+ (0.492 cmolkg^{-1}), while okra Volta recorded the lowest exchangeable K^+ value of 0.342 cmolkg^{-1}. With regards to compost and variety interactions, while Clemson recorded the highest exchangeable K^+ in unamended soil (0.322 cmolkg^{-1}), soil amended with inorganic fertilizer (0.233 cmol kg^{-1}), compost 1 (0.525cmolkg^{-1}) and compost 2 (0.885cmolkg^{-1}), Indiana recorded the highest exchangeable K in compost 3 (0.612 cmolkg^{-1}) (Figure 8.6).

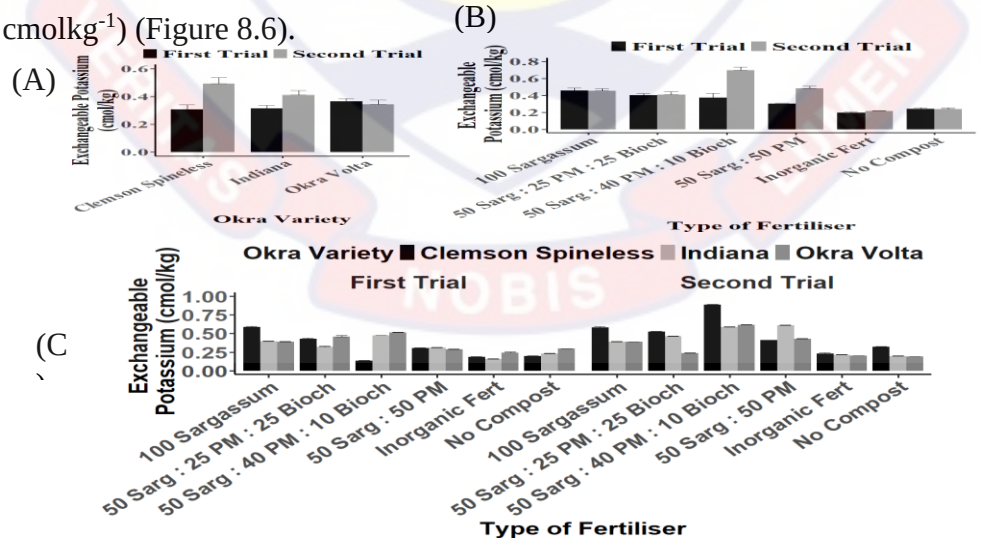


Figure 8.6: Effects of *Sargassum* compost on available phosphorus of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

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Effects of *Sargassum* compost on post-harvest soil exchangeable acidity (Al^{3+} H^{+})

In both trials, the exchangeable acidity (Al^{3+} H^{+}) of the post-harvest soil was significantly (P = 0.01) affected by *Sargassum* spp. compost application, varieties of okra and the interaction between *Sargassum* spp. compost and varieties of okra (Figure 8.7). In the first trial, compost 3 (50:50) recorded the highest Al^{3+} H^{+} value (0.189 $cmolkg^{-1}$), followed by compost 1 (50:25:25) (0.174 $cmolkg^{-1}$). For the okra variety, Clemson spineless obtained the highest $Al^{3+}H^{+}$ value (0.177 $cmolkg^{-1}$), followed by Indiana (0.174 $cmolkg^{-1}$). For treatment interactions, Clemson spineless recorded the highest Al^{3+} H^{+} value in unamended soil (0.182 $cmolkg^{-1}$), compost 3 (0.210 $cmolkg^{-1}$), and compost 4 (0.195 $cmolkg^{-1}$), while, Indiana recorded the highest Al^{3+} H^{+} value in soil amended with inorganic fertilizer (0.165 $cmolkg^{-1}$) and compost 2 (0.189 $cmolkg^{-1}$) (Figure 8.7).

In the second trial, compost 2 (50:40:10) recorded the highest Al^{3+} H^{+} value (0.218 cmolkg-^{1}), followed by compost 3 (50:50) (0.208 $cmolkg^{-1}$). With respect to the okra variety, Indiana recorded the highest $Al^{3+}H^{+}$ value (0.168 $cmolkg^{-1}$) followed by Clemson spineless (0.165 $cmolkg^{-1}$). With regards to the treatment interactions, Indiana recorded the highest Al^{3+} H^{+} value in unamended soil (0.132 $cmolkg^{-1}$), compost 1 (0.157 $cmolkg^{-1}$) and compost 3 (0.223 $cmolkg^{-1}$) while Clemson spineless recorded the highest Al^{3+} H^{+} value in soil amended with inorganic fertilizer (0.165 $cmolkg^{-1}$) and compost 4 (0.193 $cmolkg^{-1}$) (Figure 8.7)

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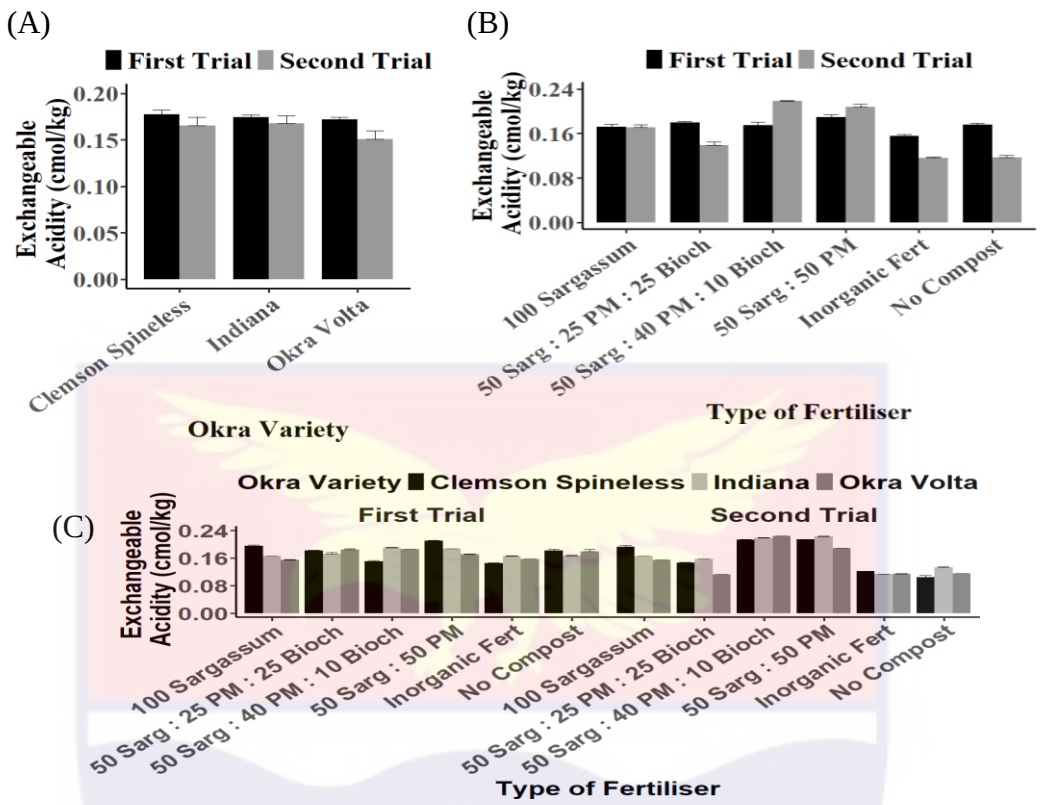


Figure 8.7: Effects of *Sargassum* compost on exchangeable acidity of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

Effects of *Sargassum* compost on post-harvest soil effective cation exchange capacity (ECEC)

In both trials, the application of *Sargassum* compost, varieties and the interactions between these two factors had a significant (P=0.01) impact on the post-harvest soil's effective cation exchange capacity (ECEC) (Figure 8.8). The total of the exchangeable bases (Na^+, K^+, Ca^{2+}, Mg^{2+}) and exchangeable acidity (Al^{3+} H^+) is the effective cation exchange capacity (ECEC). In the first trial, the highest ECEC of 8.10 $cmolkg^{-1}$ was recorded by compost 3, followed by compost 4 (8.06 $cmolkg^{-1}$). For okra varieties, Clemson spineless and okra Volta recorded the highest ECEC (6.73 $cmolkg^{-1}$). For compost and variety interactions, Clemson spineless recorded the highest ECEC in inorganic fertilizer-amended soil (4.36 $cmolkg^{-1}$), in compost 3 (10.65 $cmolkg^{-1}$) and

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compost 4 (10.12 cmolkg^{-1}). At the same time, okra Volta obtained the highest ECEC value in unamended soil (7.00 cmolkg^{-1}) and in compost 1 (7.31 cmolkg^{-1}) (Figure 8.8).

In the second trial, compost 2 recorded the highest ECEC (11.07 cmolkg^{-1}), followed by compost 3 (10.51 cmolkg^{-1}). The Clemson spineless variety obtained the highest ECEC (8.65 cmolkg^{-1}), followed by Indiana (7.71 cmolkg^{-1}). For compost and variety interactions, Clemson spineless recorded the highest ECEC value in unamended soil (4.62 cmolkg^{-1}), inorganic fertilizer amended soil (4.51 cmolkg^{-1}), compost 1 (10.44 cmolkg^{-1}), compost 2 (11.57 cmolkg^{-1}) and compost 4 (10.09 cmolkg^{-1}), while Indiana obtained the highest ECEC in compost 3 (11.85 cmolkg^{-1}) (Figure 8.8).

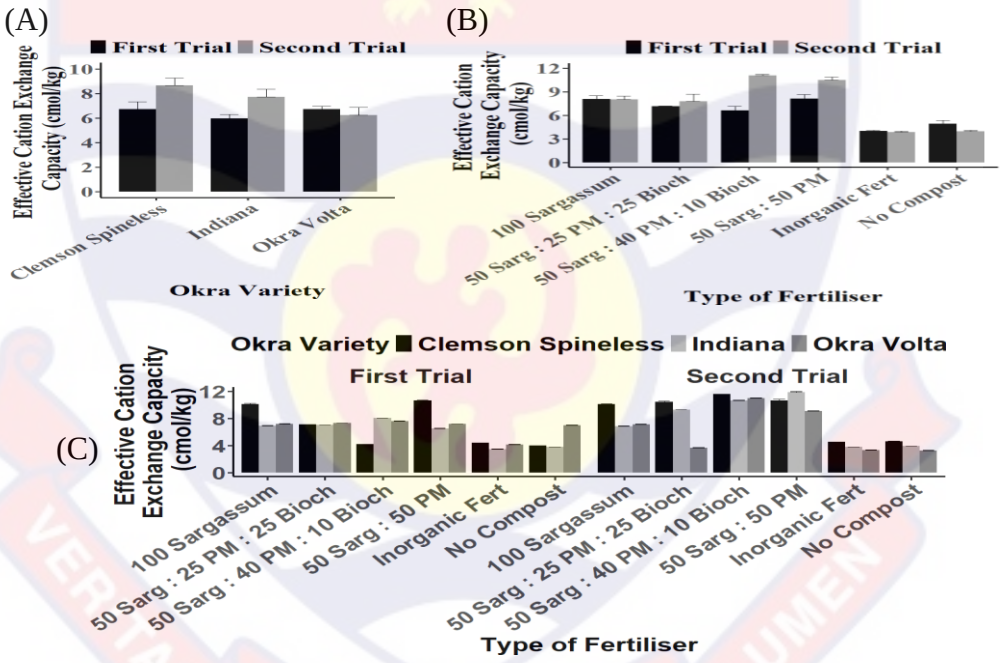


Figure 8.8: Effects of *Sargassum* compost on cation exchange capacity of post-harvest soil in the first and second trials. Data represent the mean of four (4) replicates with error bars representing the standard error of the means (S.E.M).

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Chemical properties of post-harvest soil using Pearson correlation (r) matrix in the first trial

A positive and strong significant relationship was observed in the Pearson correlation matrix between pH and available P (P = 0.01; r = 0.76), pH and exchangeable Ca (P = 0.01; r = 0.74), pH and exchangeable acidity (P = 0.01; r =0.63), pH and electrical conductivity (P = 0.01; r = 0.84), pH and effective cation exchange capacity (P=0.01; r = 0.87), pH and exchangeable K (0.01; r = 0.84), pH and exchangeable Mg (P = 0.05; r = 0.26), pH and organic carbon (P=0.01; r = 0.52), and pH and total nitrogen (P=0.01; r = 0.58) (Table 8.1). Furthermore, a positive and strong significant relationship was found in the correlation matrix between organic carbon and available P (P = 0.01; r = 0.48), exchangeable Ca (P = 0.01; r = 0.40), exchangeable acidity (P = 0.01; r = 0.64), electrical conductivity (P = 001; r = 0.34), exchangeable K (P = 0.01; r = 0.38) and exchangeable Na (P = 0.01; r = 0.33) (Table 8.1). Additionally, EC and available P (P = 0.01; r = 0.71), EC and exchangeable Ca (P = 0.01; r = 0.69), and EC and exchangeable acidity (P = 0.01; r = 0.53) all exhibited positive and highly significant relationships in the correlation matrix. There was also a positive and strong significant relationship between ECEC and available P (P = 0.01; r = 0.87), between EC and exchangeable Ca (P = 0.01; r =0.90) and between ECEC and exchangeable acidity (P =0.01; r = 0.71) and between ECEC and EC (P = 0.01; r = 0.84) (Table 8.1).

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Table 8.1: Chemical properties of post-harvest soil using Pearson correlation (r) matrix in the first trial

	pH	EC	OC	TN	AVP	Exc. K	Na^+	Mg^{2+}	Ca^{2+}	EA	ECEC
pH	-										
EC	0.84**	-									
OC	0.52**	0.34**	-								
TN	0.58**	0.56**	0.28*	-							
AVP	0.76**	0.71**	0.48**	0.59**	-						
Exc. K	0.84**	0.83**	0.38**	0.69**	0.75**	-					
Na^+	0.83**	0.76**	0.33**	0.37**	0.64**	0.63**	-				
Mg^{2+}	0.26*	0.41**	0.03ns	0.44**	0.13ns	0.40**	0.04ns	-			
Ca^{2+}	0.74**	0.69**	0.40**	0.32**	0.73**	0.56**	0.58**	0.25*	-		
EA	0.63**	0.53**	0.64**	0.39**	0.79**	0.53**	0.46**	0.03ns	0.64**	-	
ECEC	0.87**	0.84**	0.48**	0.56**	0.87**	0.76**	0.70**	0.36**	0.90**	0.71**	-

* = significant at P = 0.05 and** significant at P = 0.01, ns – not significant

AVP = available phosphorus; Ca, Na, K, Mg = exchangeable calcium, sodium, potassium and magnesium; EA = exchangeable acidity; TN = total N; OC = organic carbon; ECEC = effective cation exchange capacity

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Chemical properties of post-harvest soil using Pearson correlation (r) matrix in the second trial

The correlation matrix revealed that there was a positive and strong significant relationship between pH and available P (P = 0.01; r = 0.72), pH and exchangeable Ca (P=0.01; r =0.81), pH and exchangeable acidity (P = 0.01; r = 0.32), pH and electrical conductivity (P = 0.01; r = 0.51), pH and effective cation exchange capacity (P = 0.01; r = 0.82), pH and exchangeable K (0.01; r = 0.73), between pH and exchangeable Mg (P=0.05; r =0.71), between pH and exchangeable Na (P = 0.01; r = 0.65), between pH and organic carbon (P = 0.01; r = 0.49), and between pH and total nitrogen (P = 0.05; r = 0.30) (Table 8.2). In addition, the correlation matrix indicated a positive and strong significant relationship between organic carbon and available P (P = 0.01; r = 0.67), between organic carbon and exchangeable Ca (P = 0.01; r = 0.69), between organic carbon and electrical conductivity (P = 001; r = 0.48), between organic carbon and effective cation exchange capacity (P = 0.01; r = 0.69), between organic carbon and exchangeable K (P = 0.01; r = 0.68) and between organic carbon and exchangeable Mg (P=0.01; r =0.64 and between organic carbon and Na (P = 0.01; r = 0.67) (Table 8.2). Furthermore, the correlation matrix showed a positive and strong significant relationship between EC and available P (P = 0.01; r = 0.58), between EC and exchangeable Ca (P = 0.01; r = 0.60). There was also a positive and strong significant relationship between ECEC and available P (P = 0.01; r = 0.94), between EC and exchangeable Ca (P = 0.01; r = 0.99) and between ECEC and exchangeable acidity (P= 0.01; r = 0.30) and between ECEC and EC (P = 0.01; r = 0.67) (Table 8.2).

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Table 8.2: Chemical properties of post-harvest soil using Pearson correlation (r) matrix in the second trial

	pH	EC	OC	TN	AVP	Exc. K	Na^+	Mg^{2+}	Ca^{2+}	EA	ECEC
pH	-										
EC	0.51**	-									
OC	0.49**	0.48**	-								
TN	0.30*	0.28*	0.67**	-							
AVP	0.72**	0.58**	0.67**	0.52**	-						
Exc. K	0.73**	0.86**	0.68**	0.43**	0.83**	-					
Na^+	0.65**	0.93**	0.47**	0.20ns	0.61**	0.90**	-				
Mg^{2+}	0.71**	0.65**	0.64**	0.48**	0.83**	0.85**	0.70**	-			
Ca^{2+}	0.81**	0.60**	0.69**	0.52**	0.94**	0.86**	0.67**	0.87**	-		
EA	0.70**	0.59**	0.70**	0.48**	0.91**	0.83**	0.60**	0.90**	0.91**	-	
ECEC	0.82**	0.67**	0.69**	0.50**	0.94**	0.91**	0.75**	0.91**	0.99**	0.91**	-

* = significant at P =0.05 and **significant at P = 0.01, ns – not significant

P= available phosphorus; $Ca^{2+,}$ Na^+, K^+, Mg^{2+}= exchangeable calcium, sodium, potassium and magnesium; Al^{3+}+H= exchangeable acidity; TN= total N; OC= organic carbon; ECEC= effective cation exchange capacity

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Discussion

Post-harvest soil pH in the first and second trials

The study's results demonstrated a highly significant influence of compost on the pH of post-harvest soil. This may be because base-forming cations allowed compost to be applied to acidic soil to raise its pH (Erhart & Hartl, 2010; Leroy *et al*., 2007). Increased exchangeable bases may also cause a higher pH after applying compost. According to Banuwa *et al*. (2020), the mineralization of compost releases alkaline cations. Numerous studies have documented increased pH in soil with added compost (Castilo *et al*., 2004; Buttler & Muir, 2006). Compost had complex capacity for humic acids (Bulluck *et al.*, 2002) and buffer capacity (Leifeld *et al*., 2002). In line with this study, Wang *et al.* (2019) and Liu *et al.* (2021) posited that adding organic manure to these soils would increase their pH. According to Castillo *et al*. (2004), adding compost to a Utisol for two years could raise pH by up to 0.34 units.

Post-harvest soil electrical conductivity (EC) in the first and second trials

The study's findings showed that compost had a highly substantial impact on post-harvest soil's electrical conductivity. This may be as a result of the decomposition of organic manure, which could have released soluble salts into the soil to increase its electrical conductivity and created certain organic acids as a result of microbial activity. The results of this study are in line with those of Mussaddiq *et al*. (2019) who observed variations in soil pH and EC following the addition of mineral fertilizers and organic manures. Green compost was added, and Sarwa *et al*. (2010) reported that this increased the soil's pH and EC.

Post-harvest soil organic carbon (OC) in the first and second trials

The study's findings showed that compost had a significant effect on the organic carbon (OC) of post-harvest soil. This work supports the findings of Wang *et al.* (2019)

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who found that the organic carbon content of soil may be considerably increased by using organic manure. The study of Michael *et al.* (2012) who treated soil with kraal compost, is validated by the increase in organic carbon in the soil upon adding compost. However, the findings of this investigation differ from those of Celik *et al.*, (2004) and Wahba (2003), who found no increase in SOC levels with the addition of compost. In line with the results of the current study, the application of compost derived from domestic waste and manure resulted in a significant rise in organic carbon, with compost treatment proving to be the most successful (Bouajila & Sanaa, 2011).

Post-harvest soil total nitrogen (TN) in the first and second trials

This study revealed a highly significant influence of compost on post-harvest soil total nitrogen (TN). Comparing the TN of the modified and composted soil, the soil treated with inorganic fertilizer had a lower value. This could be due to the immediate release of nitrogen for plant absorption, which depleted the soil of TN. The results are in line with those of Ndor *et al*. (2015) who found that adding organic manures to mineral fertilizers could raise the amount of nitrogen and organic matter in the soil. Bouajila & Sanaa (2011) reported that the amount of N in the soil was dramatically increased by applying compost concentrations of 40 and 120 t ha^{-1}. Consistent with the findings of this study, Hernández *et al.* (2016) revealed that compost could improve the nutrients needed by plants, including TN, after lettuce crops were planted in the second cycle.

Post-harvest soil available phosphorus (P) in the first and second trials

Due to the compost's comparatively high accessible phosphorus content, applying compost also significantly increased the amount of phosphorus available in the soil. According to Stevenson (1986), salinity, aeration (availability of oxygen), and soil moisture are a few variables that influence how quickly phosphorus mineralizes

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from organic matter breakdown. Another possibility is that adding compost to the soil raised its pH, which improved the availability of phosphorus (Tubeileh & Stephenson, 2020). The optimal pH range for phosphorus availability in the soil is 6.0 to 7.5. But there may be additional influences as well, including fertilizer management, clay mineralogy and soil reaction (Tisdale *et al*., 1990). In both the first and second trials, the highest pH values were 7.6 and 7.7, respectively, favouring phosphorus availability. Maintaining organic matter was also crucial for regulating phosphorus availability (Schlecht *et al*., 2006). This study contradicts the findings of Alley & Vanlauwe (2009) who asserted that, in acid soils plant nutrients like P become less available due to the precipitation of Al and Fe ions.

Effective cation exchange capacity (ECEC)

ECEC is essential for plants to take up and utilize nutrients (Diacono & Mantemurro, 2010; Mwiti Mutegi *et al.,* 2012). Soils with high concentrations of negatively charged sites tend to be more productive because humic materials retain more cations. The basic cations such as Ca^{2+}, Mg^{2+}, Na^{2+} and K^{+} are the main cations in soils that are connected to CEC. But as the soil becomes more acidic, H^{+}, Al^{3+} and Mn^{2+} take the place of these cations (Erhart & Hartl, 2010).

All exchangeable cation parameters, such as Ca^{2+}, Mg^{2+}, Na^{2+} and K^{+} increased significantly with the application of compost, suggesting that plants considered compost to be a great source of exchangeable cations. The current study corroborated the findings of Adugna (2016), who stated that compost mineralization would release a number of nutrients including K, Ca, P, Cl and Mg, into the soil. In all the chemical parameters of the post-harvest soil tested, the null hypothesis is rejected while the alternative hypothesis which states that the post-harvest chemical properties of the soil

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cultivated with okra and amended with *Sargassum* compost differed from those of the unamended soil is accepted.

Chemical properties of post-harvest soil using Pearson correlation (r) matrix in the first and second trials

The correlation matrix revealed relationships between pH and available P (P = 0.01; r =0.76), exchangeable Ca (P = 0.01; r = 0.74), exchangeable acidity (P = 0.01; r = 0.63), electrical conductivity (P = 0.01; r = 0.84), effective cation exchange capacity (P=0.01; r = 0.87), exchangeable K (0.01; r = 0.84), exchangeable Mg (P = 0.05; r = 0.26), organic carbon (P = 0.01; r = 0.52) and total nitrogen (P = 0.01; r = 0.58) were all positively and significantly related. The aforementioned findings showed that pH and every parameter that was tested had a positive and substantial correlation. The positive correlation showed that accessible P, exchangeable Ca, Mg, K, N, OC and ECEC will all rise in response to pH increase. These metrics will likewise fall as a result of pH dropping. With r = 0.87 and the highest coefficient of determination (also the highest at 0.7569) ECEC has the strongest correlation. The study's findings demonstrated the importance of pH in allowing a specific cation to be released into the soil medium for plant absorption.

Conclusion

When the *Sargassum* compost was applied, there was a significant difference (P = 0.01) in the following parameters: pH, EC, OC available P, exchangeable K, Na, Ca, Mg, exchangeable acidity and ECEC. Comparing the soil added with inorganic fertilizer and the control, it was found that the compost-amended soil had greater pH, EC, OC, accessible P, exchangeable K, Na, Ca, Mg, exchangeable acidity and ECEC. The result also indicated that the *Sargassum* compost provided a conducive environment for microbial activities, enabling organic matter to mineralize and release nutrients slowly for crop growth and development.

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CHAPTER NINE

SUMMARY, GENERAL CONCLUSIONS AND RECOMMENDATIONS

Summary

To assess fishermen's indigenous knowledge of beaching, management and socio-economic problems of *Sargassum* spp. a structured questionnaire was employed to survey fishermen in the major fishing districts (Anloga and Ketu South) in the Volta Region (Efutu, Gomoa West, Mfantseman, Abura-Asebu-Kwamankese, and Komenda-Edina-Eguafo) in the Central region and (Sharma, Sekondi/Takoradi, Ahanta West and Nzema East) in the Western region. Fishing was a male-dominated business.

Another survey was also conducted to assess farmers' perception of organic fertilizer application, constraints of organic fertilizer use and factors leading to acceptance and buying of *Sargassum*-based compost in major crop growing districts (Anloga and Ketu South) in the Volta Region (Mfantseman and Cape Coast metropolitan) in the Central Region (Sekondi/Takoradi, Ahanta West and Nzema East) in the Western Region.

Four different composts with varying compositions were prepared to assess *Sargassum* spp. compost in process and compost quality characteristics. Before the composting, sawdust biochar was prepared to add to other feedstocks in the proportion of 50% *Sargassum*: 25% Poultry manure: 25 Biochar labelled as compost 1 and 50% *Sargassum*: 40% Poultry manure: 10% Biochar labelled as compost 2. The remaining bulking percentages were 50% *Sargassum*: 50% Poultry manure labelled as compost three and 100% *Sargassum* labelled as compost 4. A temperature graph versus days of turning the compost was drawn to monitor mesophilic, thermophilic, and cooling phases. After compost turning, samples of compost from days 3, 16, and 30 were analyzed in the laboratory for pH, EC, NH_4^+-N, NO_3^--N, TC, and TN in order to

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determine the mesophilic, thermophilic and cooling stages of the compost's breakdown when a graph was created. In the laboratory were also measured the pH, EC, Ash, TC, TN, available P, NH_4^+-N, NO_3^--N, Total Ca, Mg, K, Na, Cu, Zn, Fe, and B in the matured compost.

To determine *Sargassum* compost's nitrogen, phosphorus, and potassium mineralization dynamics, an incubation experiment was done in the laboratory for 60 days between 8th February and 7th April, 2023. Haplic Acrisol soil from one of the fields at the Alexander G. Carson Technology Centre, UCC was sampled, grounded, all undesired extraneous materials were filtered out using a 2 mm sieve, and the mixture was allowed to air-dry. Six hours after adding water on days 0, 3, 7, 14, 21, 28, 42 and 60, samples were taken. Chemical analysis was done on the fresh samples, using pH, EC, NH_4^+-N, NO_3^--N, TC, TN, available P, K, and CEC.

Two distinct pot experiments were conducted to assess the effects of composts made of *Sargassum* with varied compositions on the growth and yield of okra. The first trial began on February 5 and ran through May 14, 2023. The second trial began on May 28 and ran through September 6, 2023. A 3 x 6 factorial fitted into a Randomized Complete Block Design with four replications comprised the experimental design. The first factor included three okra varieties (Clemson spineless, Indiana and okra Volta), while the second factor included six growing media including control (soil without compost), soil amended with inorganic fertilizer, compost 1 (50:25:25), compost 2 (50:40:10), compost 3 (50:50) and compost 4 (100 *Sargassum*). Data were taken from 3 to 8 WAP for growth data, while yield data were taken during the reproductive phase of the plants.

The compost made from *Sargassum was* tested for its chemical qualities on soil cultivated to okra by air-drying, thoroughly mixing and gently crushing the soil until it

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could pass through a 2 mm sieve. The pH, total organic carbon, total N, extractable P, exchangeable bases (Ca^{2+}, $Mg^{2+,}$ and K^{+}), exchangeable acidity ($Al^{3+}H^{+}$), and effective cation exchange capacity were then measured for the <2-mm samples.

General conclusion

The main findings from the research were as follows:

1. *Sargassum* spp. was a problem to fishermen both at sea and on the coast when they were washed ashore. Most fishermen had no formal education and about 85.3% were married. Fishermen had adequate knowledge of nature, colour, texture, structure and the year and month of beaching of *Sargassum* spp. on the coast. In The Central region, 227 farmers obtained informal education, 17 had primary School education and 10 had JSS education. In the Western Region, 228 fishermen lacked formal education, 11 had primary education, 7 had JSS education, while in the Volta region, 66 had no formal education, 47 had primary school education, and 44 had JSS education. Socio-economic problems such as tourism, aesthetics and health, ecological dwindling fish catch and low income, engine propellers being destroyed, faulty propellers consuming more fuel, fishmongers not staying in business and fish nets being destroyed by *Sargassum* spp. were paramount among the fisherfolks. Hence, they endured economic hardship.
2. Most farmers were between 50 and 59 years old, while most had primary education. Furthermore, while 84.7% of the farmers married, the majority (44.7%) had 11-20 years' experience in farming. Descriptive statistics indicated that the age of farmers ranged from 20-80 years, family size ranged from 1.0-16.0, number of crops ranged from 2.0-15 crops per household and years in crop production ranged from1.0-60.0 years per household. While 91.6% of farmers

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used organic manure, 8.4% did not use organic manure. Cattle manure was the highest (28.1%) organic manure used by farmers, followed by farm yard manure (18.4%). Kendall's coefficient of concordance ranking of organic manure constraints revealed low to high as doubtful efficacy < slow release of nutrient <difficult to transport <offensive odour <bulkiness. In the Volta region, 427 farmers were willing to accept and buy *Sargassum* compost, while 14 farmers were not willing to buy. In The Central region, 142 farmers were willing to accept and buy *Sargassum* compost, while 18 were not interested in the product. However, while 359 farmers were willing to accept and buy *Sargassum* compost in the Western Region, 61 were not interested in the product. Descriptive statistics revealed that farmers were willing to buy *Sargassum* compost from GH₵ 8.0-GH₵420.0 per 50 kg *Sargassum* compost.

3. Laboratory analysis of pH for feedstock revealed the following: *Sargassum* was 7.27±0.1, poultry manure was 7.91±0.0, and biochar was 9.98±0.2. TC for *Sargassum* was 29.61±0.3%, poultry manure was 29.90±0.1% and biochar was 37.04±0.4%. Total N for *Sargassum* was 1.11±0.1%, poultry manure was 1.76±0.1%, and biochar was 0.30±0.1%. C: N ratio of *Sargassum* was 26.6±0.5, poultry manure was 17.0±1.2, and biochar was 123.9±23.5. On day 3 of composting, mesophilic temperature for Compost 1 was 39^{o}C, Compost 2 was 38^{o}C and Compost 3 and Compost 4 was 37^{o}C. On day 16 of the composting process, thermophilic temperature for compost 1 was 63^{o}C, compost 2 was 60^{o}C, compost 3 was 49^{o}C, and compost 4 was 50^{o}C. However, on day 30 of the composting process, temperatures began to drop; thus, compost 1 was 56^{o}C, compost 2 was 55^{o}C, compost 3 was 48^{o}C, and compost 4 was 47^{o}C. During compost decomposition, mesophilic pH ranged from 6.5 in Compost 4 to 7.8 in

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Compost 3, compost 2 and Compost 1. Thermophilic phase pH ranged from 6.6 in compost 4 to 7.9 in compost 1 and compost 2. However, pH in the cooling phase ranged from 6.4 in compost 4 to 7.8 in compost 1. Furthermore, in the matured compost, pH ranged from 6.5±0.1 in compost 4 to 6.9±0.0 in compost 1. EC values ranged from 8.48±0.2 μScm^{-1} in compost 1 to 15.62±0.6 μScm^{-1} in compost 4.

4. The highest values were recorded during the mineralization of *Sargassum* compost on the 7^{th} day after incubation for most parameters measured. For example, on day seven after incubation, pH ranged from 7.2 in compost 4 to 7.9 units in compost two and compost 3, EC ranged from 30.3 µS/cm in control to 149.2 µS/cm in compost 4, NH_4^+-N ranged from 49.7 μgg^{-1} in compost 3 to 78.1 μgg^{-1} in compost 4, NO_3^--N ranged from 1.29 µg/g in compost 4 to 5.8 μgg^{-1} in soil amended with inorganic fertilizer, available P ranged from 0.90 μgg^{-1} in soil without compost to 20.70 μgg^{-1} in compost 2, available K ranged from 0.38 $cmolkg^{-1}$ in compost 1 to 0.40 $cmolkg^{-1}$ in compost three and CEC ranged from 4.13 $cmolkg^{-1}$ in compost 1 to 4.44 $cmolkg^{-1}$ in compost 4. The result also indicated that the highest P, K and CEC values were released by compost two on incubation day 7. Consequently, day 7 is a suitable day to apply N, P, and K to the crop in order to maximize its supply and meet a vital point for the plant's growth and development.
5. In both experiments, compost formed of *Sargassum* spp. had a significant impact on plant height, number of leaves, internode length, petiole length, leaf area, and stem girth. This could be because the compost increased soil fertility and made water available.

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6. Okra Volta recorded the highest plant height, leaf number, leaf area and stem girth. Indiana also recorded the highest chlorophyll content from 3 WAP-8WAP. The result indicated that compost 3 took the shortest number of days to flower, highest number of fruits and single fruit weight. Compost 2, on the other hand, took the shortest number of days to 50% flowering.
7. The okra Volta variety recorded the highest number of seeds. Clemson spineless recorded the shortest number of days to flower, shortest number of days to 50% flowering and largest fruit diameter. Furthermore, Indiana recorded the highest total number of fruits plant^{-1} and single fruit weight. It can be concluded that *Sargassum* compost influenced okra growth and yield better than the inorganic fertilizer (N.P.K 23:10:5, Urea 46% N, MoP 60% K_2O, TSP 46% P_2O_5) and the control (soil without compost).
8. *Sargassum* compost significantly influenced the chemical properties of soil cropped to okra. Significant differences (P = 0.01) existed in compost, variety and compost and variety interaction effect in pH, EC, OC, TN, Available P, exchangeable Na^+ K^+, Mg^{2+}, Ca^{2+}, $Al^{3+}H^+$ and ECEC. For compost pH, it ranged from 6.2 units in soil amended with inorganic fertilizer to 7.9 in compost 1. Regarding variety, pH ranged from 7.0 units in Clemson spineless to 7.4 units in okra Volta. For compost and variety interaction, pH ranged from 7.1 in okra Volta to 7.8 in Clemson spineless in compost 3. The TN ranged from 0.083% in soil amended with inorganic fertilizer to 0.105% in compost 2.
9. Additionally, the TN ranged from 0.086% in Clemson spineless to 0.098% in Indiana. For treatment interactions, the TN ranged from 0.087% in okra Volta to 0.093% in Indiana. Regarding compost, ECEC ranged from 3.98 cmolkg-^{1} in soil amended with inorganic fertilizer to 8.10 cmolkg^{-1} in compost 3. For okra

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variety, ECEC ranged from 5.95 cmolkg^{-1} in Indiana to 6.73 cmolkg^{-1} in Clemson spineless and okra Volta. For the interaction effect, ECEC ranged from 6.52 cmolkg^{-1} in Indiana to 10.65 cmolkg^{-1} in Clemson spineless for compost 3. It can be concluded that the chemical properties of soil amended with inorganic fertilizer were lower than the rest of the treatments, possibly because plants absorbed inorganic fertilizer faster than compost, leading to fast depletion of nutrients in the soil.

Recommendations

1. Fishermen in the Elembelle districts of the Western region and the Greater Accra Region along the Atlantic Ocean should be the subjects of future investigation to authenticate *Sargassum*'s socio-economic problems to fishermen and coastal dwellers.
2. Further research should be extended to farmers in other regions and different ecological zones of Ghana to find out their organic manure application and its constraints and to sell *Sargassum* compost to ascertain their willingness to adopt it.
3. More studies should be conducted to look into the effects of different kinds of biochar, preferably corn cob and rice husk biochar co-composted with *Sargassum* and poultry manure on different crops, especially root crops and rice and other plants that require water in various soil types and agro-ecological zones.

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APPENDICES

APPENDIX A: ETHICAL CLEARANCE

UNIVERSITY OF CAPE COAST
INSTITUTIONAL REVIEW BOARD SECRETARIAT
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OUR REF: UCC/IRB/A/2016/1601
YOUR REF:
OMB NO: 0990-0279
IORG #: IORG0009096

11TH OCTOBER, 2022

Mr. Phanuel Yao Klogo
Department of Crop Science
University of Cape Coast

Dear Mr. Klogo,

ETHICAL CLEARANCE – ID (UCCIRB/CANS/2022/22)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted Provisional Approval for the implementation of your research **Influence of *Sargassum* spp. Amendments on Vegetable Crop Production in the Coastal Savanna Zone of Ghana.** This approval is valid from 11th October, 2022 to 10th October, 2023. You may apply for a renewal subject to submission of all the required documents that will be prescribed by the UCCIRB.

Please note that any modification to the project must be submitted to the UCCIRB for review and approval before its implementation. You are required to submit periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

Always quote the protocol identification number in all future correspondence with us in relation to this protocol.

Yours faithfully,

Kofi Fosu Amuquandoh
Ag. UCCIRB Administrator

ADMINISTRATOR
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST

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APPENDIX B: FISHERMEN QUESTIONNAIRE

FISHERMEN INDIGENOUS KNOWLEDGE ON THE BEACHING, MANAGEMENT AND PROBLEMS OF SARGASSUM SPP. IN SOME COASTAL COMMUNITIES IN GHANA

Greetings, participant I am a graduate student at the University of Cape Coast's School of Agriculture. In order to partially fulfill the criteria for a PhD in Crop Science, I am performing this research. I guarantee that the answers you provide will be kept completely private. I would appreciate it if you could respond to the following questions as honestly as possible.

SECTION A- SOCIO-ECONOMIC CHARACTERISTICS

1. Region……
2. District……..
3. Community/Village……
4. Age at last birthday……years
5. Sex a. Male [ ] b. Female [ ]
6. Occupation a. Fisherman [ ] b. Farmer [ ] c. Trader [ ] d. Others[ ]
7. Educational level a .No formal Education [ ] b. Primary [ ] c. JSS [ ] d. Middle school [ ] e. SSS [ ] f. Tertiary [ ] g. Any other, specify [ ]
8. Marital status a. Single [ ] b. Married [ ] c. Divorced [ ] d. Widow/widower [
9. Family income, any amount per year? ……..
10. Family size…….

SECTION B- KNOWLEDGE ABOUT SARGASSUM SPP. ALONG THE COAST

11. Have you ever seen weeds on the sea? a. Yes [ ] b. No [ ]
12. If yes, what types of weeds have you seen docking along the coast? ……
13. Have you ever seen Sargassum spp on your coast? .....
14. What are the features/characteristics of this Sargassum spp in terms of
    a. Colour……..b. texture……..
    b. Structure……..
15. What months do they appear on the coast within a year? .....
16. When was the last time you saw Sargassum spp appeared on your coast? .....
17. Does it come to the coast line in small or large quantities? a. Large [ ] b. Small
18. Can you quantify it in terms of kilogram or tonne? .....
19. Was it brought to the coast by drag fishing net or sea current? a drag fishing net [ ] b. Sea current[ ]

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20. If it is fishing net, does it occupy the entire volume or part of the fishing net? a. Entire net [ ] b. Only part of the net [ ]
21. What happen to the Sargassum spp. when they dock by either sea current or catch with net? ……..

SECTION C- BEACHING AND MANAGEMENT OF SARGASSUM SPP. IN THE COASTAL COMMUNITIES

22. When the Sargassum spp. docks on the coast, do people or vehicles come to collect them away? a. Yes [ ] b. No [ ]
23. If yes, what do you think they are going to use them for? ……
24. If no, do you leave them to rot on the coast? a. Don't leave them to rot [ ] b. Leave them to rot [ ]`c. Others, please specify……
25. Assuming you leave them to rot and start smelling do they hinder the progress of your fishing activities? ……
26. If yes, how does it affect your fishing activities? .....
27. Do you think that it is better to find uses for these Sargassum spp? a.Yes [ ] b. No [ ]
28. If yes what do you think the Sargassum spp. can be used for? .....
29. Do you know you can make organic fertilizer such as compost with it.? a. Yes [ ] b. No [ ]
30. If yes, do you know that the compost will serve as an income generating activity for you apart from fishing? a, Yes [ ] b. No [ ]
31. Will you accept assistance to manage the coastal weed into compost making? a.Yes [ ] b. No [ ]
32. If no, why won't you accept assistance? .....

SECTION D- ECONOMIC IMPORTANCE OF SARGASSUM SPP.

1. ECONOMIC PROBLEMS

33. Does the *Sargassum* spp. clog your fishing net? a. Yes [ ] b. No [ ]

34. When it clogs the net, does it tear the net? a. Yes [ ] b. No. [ ]

. 35. Do the Sargassum spp. also entangle engine propellers? a. Yes [ ] b. No [ ]

36. Does it cause your fishing boat to capsize? a. Yes [ ] b. No [ ]

37. If the above information are yes, mention any four economic problems it may cause to you

a……
b……
c……
d……,,……

2. TOURISM, AESTHETICS AND HEALTH PROBLEMS

38. Does the *Sargassum* spp. cause beach fouling which reduces access to the sea and shoreline for swimming and other activities? a. Yes [ ] b. No [ ]

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39. Does it cause irritation of skin, eyes and respiratory system from inhaling highly toxic hydrogen sulphide? a. Yes [ ] b. No [ ]

40. Does it cause risk fatality from inhaling low concentration of highly toxic gas? a. yes [ ] b. No [ ]

3. ECOLOGICAL PROBLEM

41. Does the *Sargassum* spp. cause perturbation (change in normal state) and relocation of marine species? a. Yes [ ] b. No [ ]

42. Does it cause beach erosion by removing sand inadvertently leading to depletion and possible shoreline instability? a. Yes [ ] b. No [ ]

43. Does it restrict access to sea turtles to nesting sites and forming barrier to the sea for the hatcheries? a. Yes [ ] b. No [ ]

44. Apart from the above problems what general problems does Sargassum spp cause to you?

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APPENDIX C: FARMERS' QUESTIONNAIRE

POTENTIAL FACTORS CONTRIBUTING TO THE ACCEPTANCE AND USAGE OF SARGASSUM-BASED ORGANIC FERTILIZER BY SOME CROP FARMERS IN CENTRAL AND VOLTA REGION

Greetings, participant I am a graduate student at the University of Cape Coast's School of Agriculture. In order to partially fulfill the criteria for a PhD in Crop Science, I am performing this research. I guarantee that the answers you provide will be kept completely private. I would appreciate it if you could respond to the following questions as honestly as possible.

SECTION A- SOCIO-ECONOMIC CHARACTERISTICS

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2. District……..
3. Community/Village……
4. Age at last birthday……years
5. Sex a. Male [ ] b. Female [ ]
6. Occupation a. Fisherman [ ] b. Farmer [ ] c. Trader [ ] d. Others……
7. Educational level a. No formal Education [ ] b. Primary [ ] c. JSS [ ] d. Middle school [ ] e. SSS [ ] f. Tertiary [ ] g. Any other, specify ……..
8. Marital status a. Single [ ] b. Married [ ] c. Divorced [ ] d. Widow/widower [
9. Family size…….
10. What types of crops do you produce?……
11. How many years have you been in crop production?.....
12. When do you sell your crops after harvest?……..
13. Do you make profit or run at a loss during production?.....

SECTION B-THE USE OF INORGANIC FERTILIZERS

13 Have you been using fertilizer in your cropping activities? a.Yes [ ] b. No [ ]

14 If yes, which type of fertilizer do you use? a. Inorganic [ ] b. Organic [ ]

15. Which of the following forms of fertilizer applications do you practice? a sole application of inorganic [ ] b sole application of organic [ ] c. rotating inorganic with organic [ ] d. combining inorganic with organic [ ]

16. What factors influence your use of inorganic fertilizer? a. price [ ] b. size [ ] c. fast dissolution in soil moisture [ ] d. fast release of nutrient [ ] e. Any other, specify……..

17. Is inorganic fertilizer expensive or cheap in the market? ……

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18. If it is expensive, have you been buying it for use in your farms? a. Yes [ ] b. No

19. What factors prevents/inhibits you from using inorganic fertilizers.....

20. Are you aware of some of the environmental effects of inorganic fertilizer such as?

a. environmental pollution……b. contamination of water bodies……

c. soil acidification……. d. poor yield of crop…….

e. poor shelf-life of crop……. f. soils and food poisoning…….

21. Kindly state reasons why you continue using inorganic fertilizers despite the effects listed in Q20 above……

SECTION C- RATE OF ADOPTION OF ORGANIC FERTILIZERS

22. Have you used any organic fertilizer in cultivating your crops before? a.Yes [ ] b. No [ ]

23. If yes, mention the different types of organic fertilizers you use a. poultry manure [ ] b. farmyard manure [ ] c. human excreta sludge d. cow-dung [ ] e. compost [] f. biochar [] g. any other, specify……..

24 What factors influence the choice and use of organic fertilizer? a. Cheap [ ] b. contain more nutrients [ ]c. release nutrient slowly [ ] d heal the soil [ ] e. Any other, specify ……

25. What factors prevent/inhibits your use of organic fertilizer? ……

26. What are the benefits of using organic fertilizers?.....

27 What quantity of organic fertilizers do you apply per bed per growing period? 25kg/bed……..50kg/bed…….100kg/bed…….Anyother.
Specify……..

28. Do you make profit on sales when you use either inorganic or organic fertilizer in growing crops? a. Yes when I use organic [ ] b. No when I use organic [ ] c. Yes when I use inorganic [ ] d. No when I use inorganic [ ] e. Yes when I mix both [ ] f. No when I mix both [ ]

29. Do you have access to credit to buy organic fertilizer a. Yes [ ] b. No [ ]

30. What type of credit? Cash……Kind……Both……..

31. Do you have access to extension agents a. Yes [ ] b. No [ ]

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32. What is the level of access that you have to organic fertilizers? No access……..Very limited access……Limited access…….Unlimited access…….

33. What is your perception about the fertility status of the soil you are cultivating your crops? Very fertile……..Fairly fertile……Fertile……Not fertile

34. Does consumer preference for organically grown crops affect your decision to adopt organic fertilizers? a. Yes [ ] b. No [ ]

35. Does the government fertilizer subsidy programme influence your decision to adopt organic fertilizers a. Yes [ ] b. No [ ]

36. When you use organic fertilizer only, what is the level of income that you realize?.....

37. When you use organic and inorganic fertilizer, what is your income after sales…….

38. When you use inorganic fertilizers only, what level of income do you realize after production? .....

SECTION D- RANKING OF CONSTRAINTS USING ORGANIC FERTILIZER

39. On a scale of 1-5 being the highest, how will you rank the following constraint?

a. Bulkiness…… b. offensive odour…….c. Doubtful efficacy……. d. difficult to transport……e. slow release of nutrient…….

SECTION E: FACTORS INFLUENCING ACCEPTANCE AND USE OF SARGASSUM-BASED ORGANIC FERTILIZER

40. Have you heard of Sargassum based organic fertilizers before? Yes [ ] b. No [ ]

41. Are you aware of Sargassum-based fertilizer such as compost? a. Yes [ ] b. No [ ]

42. Are you aware that Sargassum can also be developed into biochar for soil amendments? . a. Yes [ ] b. No [ ]

43. Are you aware of the following benefits of Sargassum-based organic fertilizers:

a. Suppression of plant pest population……..

b. Mineralization increase microbial activity and cation exchange capacity?.....

c. organic matter accumulation and Carbon content of soil?.....

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d. improves soil tilth and increase water holding capacity of soil?.....

e. contains many nutrients like NPK (Nitrogen, Phosphorus and Potassium) and retain soil nutrient to influence the growth and development of crops ?.....

44. Are you willing to buy Sargassum-based organic fertilizer when it is produced? a. Yes [ ] b. No [ ]

45. If yes, what factors will you look for in the produced compost?.....

46. How much will you be willing to buy 50 kg of compost? .....

47. Give reasons for your choice of price?.....

48. How much is the cost of compost in the market?.....

49. In case you preferred the Sargassum-based organic fertilizer to be packaged for sale, will it be in container? A Yes [ ] b. No [ ] Any other, specify …….

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APPENDIX D: ANOVA

Chemical properties of soil amended with *Sargassum* compost after incubation

Appendix 1: ANOVA for pH at day 0 (6 hours after adding water)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.05582	0.01861	0.98	
Compost	5	0.21573	0.04315	2.26	0.101
Residual	15	0.28603	0.01907		
Total	23	0.55758			

Appendix 2: ANOVA for pH at day 3 after incubation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.01265	0.00422	0.39	
Compost	5	0.62807	0.12561	11.70	<.001
Residual	15	0.16098	0.01073		
Total	23	0.80170			

Appendix 3: ANOVA for pH at day 7 after incubation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.064012	0.021337	5.86	
Compost	5	1.340171	0.268034	73.62	<.001
Residual	15	0.054612	0.003641		
Total	23	1.458796			

Appendix 4: ANOVA for pH at day 14 after incubation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.081212	0.027071	3.64	
Compost	5	0.484821	0.096964	13.03	<.001
Residual	15	0.111662	0.007444		
Total	23	0.677696			

Appendix 5: ANOVA for pH at day 21 after incubation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.07155	0.02385	1.05	
Compost	5	0.07479	0.01496	0.66	0.658
Residual	15	0.33923	0.02262		
Total	23	0.48556			

Appendix 6: ANOVA for pH at day 28 after incubation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.06371	0.02124	1.05	
Compost	5	1.32687	0.26537	13.10	<.001
Residual	15	0.30381	0.02025		
Total	23	1.69440			

Parameters of growth of okra as affected by *Sargassum* spp compost

Appendix 1: ANOVA for plant height (cm) during 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	24.500	8.167	2.01	
Compost	5	293.444	58.689	14.42	<.001
Variety	2	165.028	82.514	20.28	<.001
Compost.Variety	10	100.139	10.014	2.46	0.017
Residual	51	207.500	4.069		
Total	71	790.611			

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Appendix 2: ANOVA for plant height (cm) during 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	17.15	5.72	0.42	
Compost	5	1520.90	304.18	22.56	<.001
Variety	2	348.36	174.18	12.92	<.001
Compost.Variety	10	226.31	22.63	1.68	0.112
Residual	51	687.60	13.48		
Total	71	2800.32			

Appendix 3: ANOVA for plant height (cm) during 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	50.04	16.68	0.94	
Compost	5	1753.40	350.68	19.86	<.001
Variety	2	641.69	320.85	18.17	<.001
Compost.Variety	10	348.14	34.81	1.97	0.056
Residual	51	900.71	17.66		
Total	71	3693.99			

Appendix 4: ANOVA for plant height (cm) during 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	79.89	26.63	1.16	
Compost	5	2792.28	558.46	24.33	<.001
Variety	2	734.53	367.26	16.00	<.001
Compost.Variety	10	365.14	36.51	1.59	0.136
Residual	51	1170.61	22.95		
Total	71	5142.44			

Appendix 5: ANOVA for plant height (cm) 7 during WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	44.60	14.87	0.39	
Compost	5	3884.90	776.98	20.14	<.001
Variety	2	673.36	336.68	8.73	<.001
Compost.Variety	10	436.81	43.68	1.13	0.358
Residual	51	1967.65	38.58		
Total	71	7007.32			

Appendix 6: ANOVA for plant height (cm) during 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	47.49	15.83	0.39	
Compost	5	5542.79	1108.56	27.08	<.001
Variety	2	532.75	266.38	6.51	0.003
Compost.Variety	10	484.08	48.41	1.18	0.324
Residual	51	2087.76	40.94		
Total	71	8694.88			

Appendix 7: ANOVA for plant number of leaves during 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.6667	0.2222	0.50	
Compost	5	29.6111	5.9222	13.23	<.001
Variety	2	1.1944	0.5972	1.33	0.272
Compost.Variety	10	14.1389	1.4139	3.16	0.003
Residual	51	22.8333	0.4477		
Total	71	68.4444			

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Appendix 8: ANOVA for plant number of leaves during 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	7.0000	2.3333	3.50	
Compost	5	26.1667	5.2333	7.85	<.001
Variety	2	4.3333	2.1667	3.25	0.047
Compost.Variety	10	12.5000	1.2500	1.88	0.071
Residual	51	34.0000	0.6667		
Total	71	84.0000			

Appendix 9: ANOVA for plant number of leaves during 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	9.153	3.051	2.06	
Compost	5	66.736	13.347	9.00	<.001
Variety	2	2.778	1.389	0.94	0.398
Compost.Variety	10	8.722	0.872	0.59	0.816
Residual	51	75.597	1.482		
Total	71	162.986			

Appendix 10: ANOVA for plant number of leaves during 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	14.486	4.829	3.41	
Compost	5	167.125	33.425	23.59	<.001
Variety	2	12.583	6.292	4.44	0.017
Compost.Variety	10	14.417	1.442	1.02	0.442
Residual	51	72.264	1.417		
Total	71	280.875			

Appendix 11: ANOVA for plant number of leaves during 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3.708	1.236	0.47	
Compost	5	200.069	40.014	15.28	<.001
Variety	2	23.028	11.514	4.40	0.017
Compost.Variety	10	34.639	3.464	1.32	0.244
Residual	51	133.542	2.618		
Total	71	394.986			

Appendix 12: ANOVA for plant number of leaves during 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	4.778	1.593	0.61	
Compost	5	268.500	53.700	20.48	<.001
Variety	2	32.333	16.167	6.17	0.004
Compost.Variety	10	34.667	3.467	1.32	0.244
Residual	51	133.722	2.622		
Total	71	474.000			

Appendix 13: ANOVA for plant internode length (cm) during 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	15.149	5.050	4.07	
Compost	5	24.934	4.987	4.02	0.004
Variety	2	5.007	2.503	2.02	0.143
Compost.Variety	10	10.951	1.095	0.88	0.555
Residual	51	63.288	1.241		
Total	71	119.330			

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Appendix 14: ANOVA for plant internode length (cm) during 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	7.819	2.606	1.59	
Compost	5	31.125	6.225	3.81	0.005
Variety	2	4.333	2.167	1.32	0.275
Compost.Variety	10	9.167	0.917	0.56	0.838
Residual	51	83.431	1.636		
Total	71	135.875			

Appendix 15: ANOVA for plant internode length (cm) during 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	12.167	4.056	2.40	
Compost	5	49.944	9.989	5.90	<.001
Variety	2	20.861	10.431	6.16	0.004
Compost.Variety	10	13.306	1.331	0.79	0.642
Residual	51	86.333	1.693		
Total	71	182.611			

Appendix 16 ANOVA for plant internode length (cm) during 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	5.889	1.963	1.18	
Compost	5	60.111	12.022	7.25	<.001
Variety	2	25.861	12.931	7.79	0.001
Compost.Variety	10	11.972	1.197	0.72	0.700
Residual	51	84.611	1.659		
Total	71	188.444			

Appendix 17: ANOVA for plant internode length (cm) during 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	10.500	3.500	2.88	
Compost	5	73.778	14.756	12.14	<.001
Variety	2	28.361	14.181	11.66	<.001
Compost.Variety	10	11.306	1.131	0.93	0.514
Residual	51	62.000	1.216		
Total	71	185.944			

Appendix 18: ANOVA for plant internode length (cm) during 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	18.333	6.111	5.22	
Compost	5	128.444	25.689	21.96	<.001
Variety	2	41.694	20.847	17.82	<.001
Compost.Variety	10	10.972	1.097	0.94	0.507
Residual	51	59.667	1.170		
Total	71	259.111			

Appendix 19: ANOVA for plant petiole length (cm) during 3 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	5.122	1.707	1.54	
Compost	5	79.198	15.840	14.31	<.001
Variety	2	3.583	1.792	1.62	0.208
Compost.Variety	10	2.125	0.212	0.19	0.996
Residual	51	56.441	1.107		
Total	71	146.469			

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Appendix 20: ANOVA for plant petiole length (cm) during 4 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	19.694	6.565	2.55	
Compost	5	212.625	42.525	16.50	<.001
Variety	2	19.083	9.542	3.70	0.032
Compost.Variety	10	21.167	2.117	0.82	0.610
Residual	51	131.431	2.577		
Total	71	404.000			

Appendix 21: ANOVA for plant petiole length (cm) during 5 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	56.010	18.670	9.16	
Compost	5	269.156	53.831	26.42	<.001
Variety	2	41.813	20.906	10.26	<.001
Compost.Variety	10	24.562	2.456	1.21	0.310
Residual	51	103.927	2.038		
Total	71	495.469			

Appendix 22: ANOVA for plant petiole length (cm) during 6 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	42.375	14.125	5.68	
Compost	5	329.569	65.914	26.50	<.001
Variety	2	46.778	23.389	9.40	<.001
Compost.Variety	10	39.056	3.906	1.57	0.143
Residual	51	126.875	2.488		
Total	71	584.653			

Appendix 23: ANOVA for plant petiole length (cm) during 7 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	29.819	9.940	3.77	
Compost	5	290.625	58.125	22.05	<.001
Variety	2	107.583	53.792	20.41	<.001
Compost.Variety	10	34.417	3.442	1.31	0.253
Residual	51	134.431	2.636		
Total	71	596.875			

Appendix 24: ANOVA for plant petiole length (cm) during 8 WAP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	71.444	23.815	5.29	
Compost	5	442.278	88.456	19.65	<.001
Variety	2	264.361	132.181	29.37	<.001
Compost.Variety	10	36.139	3.614	0.80	0.627
Residual	51	229.556	4.501		
Total	71	1043.778			

Parameters of yield of okra as affected by *Sargassum* spp compost

Appendix 25: ANOVA for days to 1st flowering of okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	225.93	75.31	6.32	
Compost	5	79.46	15.89	1.33	0.265
Variety	2	158.25	79.13	6.64	0.003
Compost.Variety	10	88.42	8.84	0.74	0.682
Residual	51	607.82	11.92		
Total	71	1159.88			

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Appendix 26: ANOVA for days to 50% flowering of okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.00000	0.00000	0.00	
Compost	5	18.66667	3.73333	126.93	<.001
Variety	2	325.75000	162.87500	5537.75	<.001
Compost.Variety	10	134.08333	13.40833	455.88	<.001
Residual	51	1.50000	0.02941		
Total	71	480.00000			

Appendix 27: ANOVA for number of flowers of okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	35.444	11.815	1.97	
Compost	5	1406.778	281.356	46.81	<.001
Variety	2	199.694	99.847	16.61	<.001
Compost.Variety	10	99.972	9.997	1.66	0.116
Residual	51	306.556	6.011		
Total	71	2048.444			

Appendix 28: ANOVA for number of fruits of okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	23.667	7.889	1.57	
Compost	5	1269.611	253.922	50.52	<.001
Variety	2	188.694	94.347	18.77	<.001
Compost.Variety	10	90.139	9.014	1.79	0.086
Residual	51	256.333	5.026		
Total	71	1828.444			

Appendix 29: ANOVA for single fruit weight of okra per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	49.050	16.350	9.66	
Compost	5	732.228	146.446	86.51	<.001
Variety	2	10.818	5.409	3.20	0.049
Compost.Variety	10	132.843	13.284	7.85	<.001
Residual	51	86.333	1.693		
Total	71	1011.272			

Appendix 30: ANOVA for total fruit weight of okra per plant

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	19878.	6626.	4.56	
Compost	5	574095.	114819.	79.02	<.001
Variety	2	60091.	30046.	20.68	<.001
Compost.Variety	10	66518.	6652.	4.58	<.001
Residual	51	74104.	1453.		
Total	71	794686.			

Chemical properties of post-harvest soil cropped to okra

Appendix 31: ANOVA for pH of post-harvest soil cropped to okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	5.819E-04	1.940E-04	3.31	
Compost	5	2.654E+01	5.307E+00	90435.58	<.001
Variety	2	1.606E+00	8.029E-01	13680.40	<.001
Compost.Variety	10	1.436E+01	1.436E+00	24469.58	<.001
Residual	51	2.993E-03	5.869E-05		
Total	71	4.251E+01			

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Appendix 32: ANOVA for electrical conductivity (µScm^{-1}) of post-harvest soil cropped to okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3.756E-01	1.252E-01	0.99	
Reps.*Units* stratum					
Compost	5	2.632E+05	5.263E+04	4.181E+05	<.001
Variety	2	1.217E+04	6.086E+03	48350.74	<.001
Compost.Variety	10	1.105E+05	1.105E+04	87755.03	<.001
Residual	51	6.419E+00	1.259E-01		
Total	71	3.858E+05			

Appendix 33: ANOVA for available phosphorus (µgg^{-1}) of post-harvest soil cropped to okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	25.600	8.533	2.40	
Compost	5	13080.081	2616.016	736.22	<.001
Variety	2	697.253	348.626	98.11	<.001
Compost.Variety	10	22297.713	2229.771	627.52	<.001
Residual	51	181.218	3.553		
Total	71	36281.865			

Appendix 34: ANOVA for organic carbon (%) of post-harvest soil cropped to okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.005956	0.001985	1.75	
Compost	5	0.229412	0.045882	40.38	<.001
Variety	2	0.034509	0.017254	15.19	<.001
Compost.Variety	10	0.228133	0.022813	20.08	<.001
Residual	51	0.057947	0.001136		
Total	71	0.555957			

Appendix 35: ANOVA for total nitrogen (%) of post-harvest soil cropped to okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.00001637	0.00000546	0.44	
Compost	5	0.00510074	0.00102015	81.50	<.001
Variety	2	0.00171553	0.00085776	68.53	<.001
Compost.Variety	10	0.01058164	0.00105816	84.54	<.001
Residual	51	0.00063837	0.00001252		
Total	71	0.01805265			

Appendix 36: ANOVA for effective cation exchange capacity (mgkg^{-1}) of post-harvest soil cropped to okra

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.03044	0.01015	0.90	
Compost	5	171.54680	34.30936	3047.74	<.001
Variety	2	9.74571	4.87286	432.86	<.001
Compost.Variety	10	119.34927	11.93493	1060.19	<.001
Residual	51	0.57412	0.01126		
Total	71	301.24634			

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