University of Cape Coast https://ir.ucc.edu.gh/xmlui

UNIVERSITY OF CAPE COAST

ASSESSING THE POTENTIAL OF LOCAL BENEFICIAL HALOPHYTES IN DESALINATION

KWABENA AZURE SANLERI

2024

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

UNIVERSITY OF CAPE COAST

ASSESSING THE POTENTIAL OF LOCAL BENEFICIAL HALOPHYTES IN DESALINATION

BY

KWABENA AZURE SANLERI

A 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 a Master of Philosophy degree in Crop Science.

NOVEMBER 2024

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

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 in this university or elsewhere.

Candidate's Signature: .... Date: ....

Name: Kwabena Azure Sanleri

Supervisors' Declaration

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

Principal Supervisor's Signature ……………………………… Date: ....

Name: Prof. Michael Osei Adu

Co-Supervisor's Signature: .... Date: ....

Name: Dr. Kwadwo Kusi Amoah

Digitized by Sam Jonah Library

ABSTRACT

Cape Coast, part of Ghana's coastal region, has a rich diversity of plant species with various potential uses. These plant species, called halophytes, possess qualities that enable them to grow and thrive in saline environments. This research aimed to identify and explore these plants' nutritional, ecological, and medicinal significance, examining their salt tolerance and desalination abilities. The halophytes were identified using an image recognition method, where images of the plants were keyed into Pl@ntNet Identify website (https://identify.plantnet.org/), an online software for plant identification. Five halophytes, namely, *Ipomoea aquatica*, *Lactuca taraxacifolia*, *Paspalum vaginatum*, *Sesuvium portulacastrum* and *Talinum triangulare*, were selected from the identified halophytes for a greenhouse experiment using a Completely Randomized Design (CRD) to assess their response to varying salt concentrations (0, 25 and 50 dS/m) and soil types (sea sand and arable soil). Results revealed significant growth and salt tolerance variations among the studied halophytes, with *P. vaginatum* and *S. portulacastrum* demonstrating remarkable phytoremediation capabilities. These plants exhibited the ability to mitigate soil salinity and reduce the accumulation of toxic ions in soils, highlighting their potential for addressing soil and water salinity issues in affected environments. Another greenhouse experiment was conducted to assess the desalination abilities of *S. portulacastrum* (the most promising halophyte from the initial experiment) to desalinate saline water in a hydroponic system on a vertical farming structure. The factors for this experiment were the salt concentrations (0, 25 and 50 dS/m) and planting distances (15, 20, 30 and 40 cm). *Sesuvium portulacastrum* exhibited limited desalination capacity in reducing the EC and TDS of the saline water. However, it contributed to a reduction in the pH of the saline water. Further research is necessary to discover this pH-reducing effect's underlying mechanisms and potential applications in water treatment processes. Overall, this study underscores the significance of harnessing the ethnobotanical resources in Ghana for sustainable development and environmental conservation.

Digitized by Sam Jonah Library

KEYWORDS

Halophytes

Desalination

Bioremediation

Phytoremediation

Phyto-desalination

Diversity

Osmoprotectant

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

ACKNOWLEDGEMENT

First, I would like to thank God Almighty for His immeasurable grace, favour, guidance, and protection throughout my study. Special gratitude goes to my supervisors, Prof. Michael Osei Adu and Dr. Kwadwo Kusi Amoah, whose discipline, suggestions, encouragement, technical advice and guidance helped me to organize my thoughts for this project. I would also like to thank Dr. Francis Kumi for his enormous support and direction towards the good of this project, especially about the engineering aspect of the work. Also, I would like to thank Prof. Paul Agu Asare for his encouragement and mentorship towards the good of this project. God richly bless you. Again, I appreciate Mr. Kwabena Osei Agyemang's assistance with the laboratory analysis of soil and plant samples.

Additionally, I would like to express my profound gratitude to the 'Revenue diversification pathways in Africa through bio-based and circular agricultural innovations – DIVAGRI' for funding this research.

Again, I would like to thank my senior colleague, Mr. Vincent Agyemang, for his great assistance and selfless act towards the good of this work. Also, I wish to express my sincere gratitude to my colleagues, Mr. Samuel Addo Banafo, Godswill Hygienus, Solomon Amamu, Godfred Okyere-Pra, as well as all members of Adu's Lab for their assistance in the set-up of the work and during the most difficult parts of the work. God bless you all.

Finally, a genuine appreciation goes to my family, especially my beloved wife Mrs. Diana Agyeiwaa Sanleri, my guardians, Mr. Peter and Mrs. Rebecca Issah Seidu and my brother, Mr. Bright Azure Sanleri, for their immense support, wise counsel and prayers.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

DEDICATION

I dedicate this work to God Almighty and to my late parents, Mr. Sanleri and Mrs. Nyapoka Azure Logte. You will forever remain in my heart.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

TABLE OF CONTENTS

Digitized by Sam Jonah Library

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

LIST OF TABLES

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

LIST OF FIGURES

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

LIST OF ACRONYMS

ANOVA	Analysis of Variance
CRD	Completely Randomized Design
IEA	International Energy Agency
RCBD	Randomized Complete Block Design
USDA	United States Department of Agriculture
LSD	Least Significant Difference
UNWWD	United Nations World Water Development
UN-DESA	United Nations-Department of Economic and Social Affairs
ROS	Reactive Oxygen Species
HKT	High-Affinity Potassium Transporter
ICAR-CSSRI	Indian Council of Agricultural Research - Central Soil Salinity Research Institute

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to Study

The rapid growth of the world population and the increase in living standards have resulted in increased demand for essential resources, such as water, food, soil, and energy (Turcios *et al.,* 2021). Additionally, the demand for freshwater is increasing for residential, industrial, and agricultural uses, along with a decline in the availability of potable water (Karagiannis and Soldatos, 2008). This accelerated demand for fresh water has led to the overexploitation of natural resources. Crop production has been hampered due to freshwater shortages caused by inadequate precipitation and poor water management practices (Turcios *et al.*, 2021).

Although it is estimated that by 2050, there will be an increase of about 55% in demand for water worldwide, the agricultural sector is expected to produce 100% more food in developing countries and 60% in developed countries (United Nations World Water Development, UNWWD, 2015). There is a need to increase the yields of various crops by about 50% to meet the 70-100% increase in food demand (Godfray *et al.,* 2010). In addition, there is a predicted 45% increase in demand for water in coastal regions, which is likely to result in salinity due to ground water exploitation (Indian Council of Agricultural Research - Central Soil Salinity Research Institute, ICAR_CSSRI, 2015). Furthermore, factors like global climate change, rapid urbanization, diverting agricultural lands for non-agricultural purposes, and the alarming decline in soil organic carbon contribute to the

Digitized by Sam Jonah Library

increasing problem of soil salinity resulting in reduced crop productivity (Lal, 2004; Fahad and Wang, 2018).

Nearly 43% of the Earth's land is classified as arid or semi-arid, and as a result, 98% of water in these areas is saline (Quichimbo *et al.,* 2020). Globally, salinity affects more than 800 million hectares of land. Also, nearly 20% of prime irrigated agricultural lands, covering 46 million hectares, have become saline (Pitman and Läuchli, 2002). This situation has resulted in economic losses reaching US$ 27.3 billion annually (Qadir *et al.*, 2014). As arable lands and water resources decrease, salinity issues are escalating, and agricultural inputs are reported to contribute most to the 80 million ha of land area affected by salt globally (Wedekind, 2014).

Soil conditions greatly influence water and air movements, making it challenging for major crops and trees to grow in these soils due to their low salt tolerance (Glenn *et al.,* 1999). It is essential to explore environmentally-friendly practices and techniques to prevent further salinization. Practices involving the use of biological organisms through bioremediation and desalinization hold promise. Bioremediation involves the detoxification, stabilization, or removal of toxic contaminants from soil and water through the actions of living organisms, such as fungi, bacteria, actinomycetes, and plants (Bernardino *et al.,* 2020; Joshi *et al.*, 2019). Phytoremediation, a subset of bioremediation, employs plants and plant-associated microorganisms to remove contaminants from soil and water (Bernardino *et al.,* 2020). Phytodesalination is a plant-based method that effectively

Digitized by Sam Jonah Library

eliminates excessive salt from polluted areas, allowing the land to be restored for cultivation (Srivastava, 2020). This economically viable and environmentally sustainable approach provides a cost-effective means of remediating salt-affected regions.

Cultivating salt-tolerant crops becomes crucial to ensure sustainable agricultural production on saline soils (Rozema and Flowers, 2008; Joshi *et al.,* 2015). Halophytes, salt-tolerant plants, are vital in producing food, feed, marketable products, and renewable energy from biomass (Turcios *et al.,* 2021). Halophytes exhibit significant potential in restoring salt-stressed lands, remediating contaminated soils and desalinating saline water (Sharma *et al.,* 2016). However, very little has been done in the Ghanaian context to explore the potential of local halophytes to remediate salt-affected soils and desalinate saline water.

1.2 Problem Statement

The continuous growth of the global human population is being projected by the United Nations' to reach 9.7 billion people by 2050, which would lead to increase in the demand for food and water (United Nations-Department of Economic and Social Affairs, 2019). Although about 71% of the earth's surface is covered with water, the oceans (saline and unsuitable for domestic purposes) hold approximately 97% of it. Only about 3% of Earth's water is freshwater; 69% resides in ice caps or glaciers, 30% is underground, and less than 1% is located in lakes, rivers, and swamps (Water Science School, 2019). Therefore, a relatively small portion of freshwater is available to sustain human, plant and animal life.

Digitized by Sam Jonah Library

Over 700 million people currently do not have access to potable water, and by 2025, this figure is estimated to rise to 3 billion (UNWWD, 2015). Also, there are over 800,000 deaths per year resulting from the insufficient availability of clean water, mainly among children, and over 80 countries are experiencing serious water shortages, which may spread throughout the globe shortly (Karagiannis and Soldatos, 2008). This challenge is further worsened by unpredictable climate changes, leading to different abiotic stresses, including salinity, drought, heat, and high temperature. These stresses harm agricultural sustenance and productivity (Fahad *et al.,* 2017).

The situation is exacerbated in Ghana due to the escalating rate of illegal mining, known as "Galamsey," which threatens water bodies and arable lands in Ghana (Darko *et al.,* 2021). Illegal mining activities have caused severe pollution in Ghana's major rivers, namely Ankobra, Asesree, and Pra, previously relied upon as primary water sources by neighbouring communities (Mensah *et al.,* 2015).

Considering the limited options available, producing freshwater from saline water through desalinization and bringing saline, sodic, and other barren lands into cultivation is necessary. Additionally, safeguarding the limited water resources is crucial to meet the growing food demand and address the escalating climatic and ecological concerns.

1.3 Justification

Climate change has resulted in rising of sea levels and scarcity of drinking water. Simultaneously, soil salinity concerns, resulting from the accumulation of

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

soluble salts like sodium and chloride in soils, has become a recognized global issue (Saddhe *et al.,* 2019; Nikalje *et al.,* 2018; Srivastava, 2020).

There is a growing necessity to explore desalination processes for obtaining drinking water from seawater and reclaiming saline soils to address these challenges. However, the current technologies for producing drinking water from brackish water have drawbacks, including high initial investments, substantial energy consumption, and a lack of skilled labour (Arámburo-Miranda and Ruelas-Ramírez, 2016). Similar limitations are observed in attempts to reclaim saline/sodic soils where practices such as applying anti-saline substances, leaching of soil and subsequent drainage and seed priming (Qureshi *et al.,* 2007; Khan *et al.*, 2010), and the use of salt-tolerant crop varieties have been marginally adopted.

To overcome these problems, several researches, including that of Zhao *et al.,* 2001, 2005; Tester and Davenport, 2003; Graifenberg *et al.,* 2003; Rabhi *et al.,* 2009; 2010a; 2010b and Ravindran *et al.,* 2007, have encouraged a more biological approach that demonstrates the ability of plants in desalinizing soils and removing noxious organic compounds, leachates from landfills, and heavy metals including arsenic, mercury, and lead as well as pesticides from polluted sites (Joshi *et al.,* 2019; Kushwaha *et al.,* 2015). This process is known as bioremediation, or more precisely, phytoremediation.

Halophytic species, classified by Steiner (1935) as succulent, non-succulent, and accumulating halophytes, present possibilities for remediating salt-contaminated areas and desalinating saline or brackish water for bio-saline agricultural purposes (Manousaki and Kalogerakis, 2011). Succulent halophytes

Digitized by Sam Jonah Library

can withstand elevated chloride levels in their cell sap, non-succulent halophytes eliminate excess salt through salt glands, and accumulating halophytes store surplus salt in vacuoles and cell walls, which eventually results in the shedding of leaves.

Unlike glycophytes, halophytes can thrive and develop in salty areas with salt concentrations of about 200 mM NaCl without affecting their lifecycle (Flowers and Colmer, 2008). Cultivating halophytes allows for the utilization of seawater without compromising biomass or seed production and, as a result, ensures food security in saline-affected regions. Additionally, halophytic biomass can produce biogas, providing renewable energy sources. As a result, there has been an increase in the cultivation and valorization of halophytes, especially in arid areas where brackish water is the only alternative for fresh water due to fresh water scarcity (Turcios *et al.,* 2021). Halophytes' economic viability and ability to thrive in saline soils make their cultivation advantageous. Moreover, the sustainable processing of halophytic biomass offers opportunities for producing high-quality feed ingredients, food, and bioactive products on a commercial basis through efficient conversion and valorization methods (International Energy Agency (IEA), 2007).

Despite the advantages of halophytes and Ghana's proximity to the sea, very little research has been conducted in this area. Consequently, it is crucial to identify halophytes in Ghana and assess their potential for remediation of salt-affected soils and desalination of saline water and contaminated water bodies.

Digitized by Sam Jonah Library

1.4 Objectives of Study

1.4.1 General Objective

The overall objective of this study is to assess the salt tolerance and growth performance of beneficial local halophytes in Ghana and their potential for desalination.

1.4.2 Specific Objectives

Specifically, this study seeks to:

1. Assess the diversity of halophytes along the Atlantic Ocean in Cape Coast, Ghana.
2. Evaluate the growth performance of selected beneficial halophytes under varying salt concentrations and soil types.
3. Investigate the potential of the most salt-tolerant halophyte in desalinating saline water and accumulating biomass in a hydroponic system.

1.5 Research Hypotheses

The null hypotheses for the study are:

1. There is no significant variation in the types of halophytes found along the Atlantic Ocean coastline in Cape Coast and their respective salt tolerance levels.
2. Salinity does not significantly affect the growth, biomass allocation, or ion accumulation in halophytes grown under controlled conditions.
3. Halophytes do not significantly reduce the electrical conductivity (EC), total dissolved solids (TDS), or pH of saline water in hydroponic systems.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

1.6 Expected Outcomes

At the end of the study, I should have:

- determined the morpho-physiological response of selected beneficial halophytes to salt stress.
- identified the beneficial halophyte, which is most tolerant of salt stress.
- assessed the potential of halophytes to desalinate brackish, sodic or saline water and produce pure water for crop production.
- identified halophytes with exceptional salt tolerance traits for breeding salt-resistant staple crops in Ghana.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction to Halophytes

The global challenges with freshwater scarcity and increasing salinity in soils and water sources have increased interest in studying halophytes. Halophytes are plants adapted to grow in saline environments (Flower and Colmer, 2008). The term "halophyte" originates from the Greek words; "halo", which means salt and "phyton", meaning plant.

Halophytes have evolved unique physiological and biochemical mechanisms that allow them to thrive in saline environments such as near-shore shallows, estuaries, coastal salt marshes, inland salt lakes, and saline desserts (Flowers and Colmer, 2008; 2015). They can absorb, tolerate and compartmentalize salts. These characteristics distinguish them from glycophytes, which are plants unable to survive in highly saline environments (Flower and Colmer, 2008). Halophytes possess diverse adaptation mechanisms that allow them to maintain water balance, regulate osmotic pressure and cope with salt stress. These adaptations include specialized salt glands, efficient ion transport systems, and modifications in leaf anatomy. Aside from their ability to survive in saline environments, halophytes play an essential role in ecological restoration, soil stabilization and biodiversity conservation. Halophytes play a significant role in mitigating the effects of climate change as they are employed in soil reclamation and erosion control practices.

As the literature on halophytes continues to grow, halophytes are seen to be a valuable resource for mitigating water scarcity challenges and reclaiming saline

Digitized by Sam Jonah Library

soils. This review explores the current state of knowledge regarding halophytes and the potential they hold for desalination. As part of this review, various aspects of halophyte research, including growth performance and salt tolerance mechanisms, are discussed.

2.2 Classifications and Types of Halophytes

Halophytes may be classified based on several characteristics. They are:

2.2.1 Ecology:

Sengbusch, in 2003, classified halophytes based on their ecological traits. He categorized them as either obligate, facultative or habitat-indifferent halophytes. The characteristics of these types of halophytes are described below;

(i) **Obligate halophytes:** These are halophytes that exclusively thrive in saline environments. They can exhibit vigorous growth under high saline conditions. They are primarily plants from the *Chenopodiceae* family. An example of such halophytes is *Salicornia bigelovii*

(ii) **Facultative halophytes:** Facultative halophytes can grow under both salty and salt-free soils. They, however, grow satisfactorily under salt-free soil conditions. They include species of the *Brassicaceae*, *Poaceae* and *Cyperaceae* families.

(iii) **Habitat-indifferent halophytes:** This category comprises plants that are indifferent to habitat specificity. They typically inhabit salt-free soils yet can thrive in saline soils when necessary. Examples are *Potentilla anserina, Myosurus minimus* and *Chenopodium glaucum.*

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

2.2.2 Tolerance Mechanism:

Halophytes may also be classified based on their tolerance mechanism. According to Walter (1961), halophytes can be classified as salt excluders, excreters or accumulators.

(i) **Salt accumulators:** This cluster of halophytes accumulates substantial salt concentrations in their cells and tissues, storing salt far from actively growing cells. Examples of these halophytes are*; Sesuvium portulacastrum, Suaeda nudiflora, Sonneratia spp., Excoecaria agallocha, Limnitzera racemosa*, and *Salvadora persica.*

(ii) **Salt excreters:** This halophyte group regulates internal salt concentrations by excreting salts through specialized salt glands. They include; *Acanthus ilicifolius, Aegiceras corniculatum* and *Avicennia spp.*

(iii) **Salt excluders:** These halophytes employ an ultrafiltration mechanism within their root systems to prevent excessive salt intake. Mangrove vegetation such as *Kandelia candel*. *Rhizophora mucronate, Bruguiera gymnorrhiza* and *Ceriops candolleana* are examples of such halophytes.

2.2.3 Habitat:

Halophytes can be categorized based on their habitat preference. They are categorized as either hydrohalophytes or xerohalophytes (Youssef, 2009).

(i) **Hydrohalophytes:** Hydrohalophytes are halophytic plants that flourish in aquatic environments. Coastal salt marsh species and mangroves are examples of such plants.

Digitized by Sam Jonah Library

(ii) **Xerohalophytes:** On the other hand, this group is made up of halophytes that grow in arid conditions with low soil moisture content and saline soils. They are mostly made up of plant species in desert regions.

2.2.4 Level of Salt Tolerance:

The classification of halophytes based on their tolerance to salt levels, as described by Chapman (1942), provides a basis for understanding their response to varying saline environments. He categorized halophytes as either miohalophytes or euhalophytes.

(i) **Miohalophytes:** These halophytes grow in low salinity levels, where the salt concentration remains lower than 0.5% NaCl.

(ii) **Euhalophytes:** Euhalophytes are halophytes that grow in environments with high salinity levels. They are further classified into subgroups based on their capacity to endure specific salt concentrations:

a) **Mesohalophytes**- These plants can tolerate salinity levels ranging from 0.5 to 1%. They are adaptable to moderately saline conditions.

b) **Eneuhalophytes** - These plants have evolved mechanisms that enable them to thrive in salinity levels beyond 1%. They cannot only survive but thrive in such extreme salt concentrations.

c) **Mesoeuhalophytes-** These halophytes can grow in a relatively higher salt environment with salt concentrations of 5% and above.

Digitized by Sam Jonah Library

2.3 Uses of Halophytes

Halophytes have garnered increasing attention for their diverse applications in various fields. They present various benefits ranging from environmental sustainability to serving as a source of nutrition and medicine. These diverse uses of halophytes are discussed below.

2.3.1 Applications in Crop and Animal Production

Edible halophytes may be used as food in salt-affected areas and have shown promise in addressing global food security challenges. Munns and Tester (2008) highlighted the potential of halophytes, including quinoa (*Chenopodium quinoa*) and sea barley (*Hordeum marinum*), as alternative crops for saline soils. According to Suarna and Wijaya (2021) and Morris (2023), *Clitoria ternatea*, a perennial vine which belongs to the Fabaceae family, has edible flowers which possess nutritional values and can be used as tea and for food colouring. Also, Malakar *et al.* (2015) also reported on using *Ipomoea aquatica* leaves for culinary dishes. Adebisi (2004) and Adinortey *et al.* (2012) also reported on using *Lactuca taraxacifolia* for salad and its nutritional significance in the human diet. Different species of *Physalis spp.* have also been reported by Daunay *et al.* (2007) to be edible fruits with significant nutrients. Reports by He *et al.* (2022) have highlighted the significant nutritional qualities possessed by *Sesuvium portulacastrum.* The widely used *Cocos nucifera* has gained great attention due to its diverse qualities, especially its edible fruits and oils, as Pham (2016) reported. Another research study by Pavithra *et al.* (2017) emphasized the culinary uses of *Talinum triangulare,* especially in Western Africa.

Digitized by Sam Jonah Library

Some halophytes are used as fodder and forage in arid and semiarid regions. They offer a critical solution for providing sustenance in dryland ecosystems. Halophytic forages and fodder comprise grasses such as *Sporobolus, Hedysarum, Paspalum, Spartina, Thinopyrum* and *Puccinellia;* trees including *Acacia, Salvadora, Prosopis* and *Leucaena leucocephala;* and shrubs including *Salsola, Suaeda* and *Atriplex.* A study by Morris (2023) reported on the use of *Clitoria ternatea* for forage. Also, *Indigofera spicata* was reported by Heuzé *et al.* (2016) as an essential source of nutrition for livestock. Apart from its edible fruits, *Opuntia spp.* has been used as forage for livestock, as Fabbri *et al.* (2016) and Parker (2022) emphasised.

These halophytes offer various nutritional benefits, making them suitable for sustainable agriculture. However, only a few of these halophytes have been extensively studied and successfully implemented on a large scale. Therefore, further research is needed on optimizing cultivation practices and addressing potential challenges.

2.3.2 Bioenergy Production

Some halophytes have been reported to produce biomass for biofuel. Hulkko *et al.* (2022) investigated the potential of *Salicornia europaea, Tripolium pannonicum and Crithmum maritimum* in bioenergy production. They reported that *Salicornia europaea* can accumulate biomass under saline conditions, which can be used to produce bioethanol. Christiansen *et al.* (2021) studied *Salicornia bigelovii* under saline aquaculture effluents and stated that the plant can produce about 2500 L/ha of bioethanol as it contains highly digestible carbohydrates. Research by

Digitized by Sam Jonah Library

Abideen *et al.* (2011; 2014) also revealed that *Euphorbia tirucalli*, *Ricinus communis*, *Suaeda aralocaspica*, *Descurainaia sophia* and *Salicornia bigelovii* can store up to over 20% of their total tissue dry weight as oils. Also, *Ricinus communis* has been reported by Zhou *et al.* (2010) to accumulate as high as 40% of its seed dry biomass as oils.

The use of halophytes for bioenergy production has not been much exploited due to their low biomass yields and energy-intensive processing methods. It is important to address these limitations to maximise halophytes' bioenergy potential.

2.3.3 Environmental Conservation

Halophytes play a vital role in environmental conservation, restoring degraded ecosystems and controlling soil erosion. Mendoza-Gonzalez *et al.* (2014) reported on the application of *Canavalia rosea* in preventing soil erosion and enhancing the geomorphology of beaches and dunes. Lin *et al.* (2021) also detailed the ability of the plant to adapt to extreme environments such as drought conditions. Also, a report by Zou *et al.* (2022) highlighted the ability of *Canavalia rosea* to tolerate extreme environments, especially that of tropical islands, due to its thermotolerance ability resulting from the metallothionein in the plant's tissues. The study again emphasized the role of metallothionein in conferring tolerance to soil heavy metals on *Canavalia rosea*. Another report by Casierra-Martínez *et al.* (2017) and Fontalvo *et al.* (2011) revealed the erosion control and phyto-depuration abilities of *Cyperus ligularis*, a perennial halophyte belonging to the Cyperaceae family, under wetland habitat. *Indigofera spicata* has also been reported by Heuzé

Digitized by Sam Jonah Library

et al. (2016) to possess soil improvement qualities and is usually planted as green manure and used as a cover crop in rubber, tea and coffee plantations.

Similarly, Burkill (2004) highlighted using *Ipomoea asarifolia* as ground cover and its role in binding dunes. Another study by Fabbri *et al.* (2016) found that *Paspalum vaginatum* played a significant role in controlling soil erosion and has been widely used as a turfgrass. *Pupalia lappacea*, a herbaceous annual plant belonging to the Asteraceae family, was identified by Barkhadle *et al.* (1994) for its role in controlling soil erosion on heavily degraded vegetation in Southern Somalia. Furthermore, a review by Lokhande *et al.* (2013) on *Sesuvium portulacastrum* emphasized the significant role of the plant in ensuring soil stabilization, especially in salt-affected areas. *Canavalia rosea* has also been reported by Lin *et al.* (2021) to possess the ability to fix atmospheric nitrogen in the soil, thereby enhancing soil productivity.

Although several research studies have approached the significant role of halophytes in maintaining environmental conservation, the success of the application of these halophytes has been very minimal, leaving much to be expected. Further investigations are required to complement existing findings and identify the most effective halophyte species for specific restoration purposes.

2.3.4 Phytoremediation and Desalination

Halophytes show great promise for restoring salt-damaged soils and cleaning up contaminated ones. Since they absorb salts from the soil and store them in their tissues, salt-accumulating halophytes play a significant part in

Digitized by Sam Jonah Library

phytoremediation and soil salinity mitigation. Shabala and Pottosin (2014) shed light on halophytes' mechanisms to tolerate and exclude salts. Research by Flowers *et al.* (2010) emphasizes the importance of halophytes for soil remediation, as they can actively remove salts and contribute to rehabilitating salt-affected soils without negatively affecting the environment. *Ipomoea aquatica* was found by Rai and Sinha (2001) to accumulate increased amounts of metals in their tissues when irrigated with water containing high amounts of metals, revealing their potential in remediating degraded soils.

Also, Islam *et al.* (2019) tested the desalination abilities of *Ipomoea aquatica*, *Alternanthera philoxeroides* and *Ludwigia adscendens*. They found that vacuole sequestration and cells in the xylem vessels and leaves of these plants were probably responsible for the desalination ability of these halophytes as they accumulated Na in their stems. Findings by Tripathi *et al.* (2021) revealed that *Pedalium murex,* along with *Sesbania bispinosa* and *Momordica doica* can accumulate increased concentrations of Mn, Fe, and Ni in their roots, making them suitable for phytoaccumulation of heavy metals at degraded sites. Investigations on *Sesuvium portulacastrum* by Ayyappan *et al.* (2016) discovered that the plant could remove heavy metals such as Cr, Cd, Cu and Zn as well as Na and Cl from highly contaminated soils, demonstrating its phytoremediation potency. Other halophytes, including *Suaeda salsa, Portulaca oleracea, Parkinsonia aculeata* and *Juncus rigidus* have been reported to possess very strong remediations abilities.

A major setback to this avenue is the energy efficiency of desalination processes and the identification of suitable halophytes with remediation qualities.

Digitized by Sam Jonah Library

These challenges need to be addressed to realise halophytes full potential in sustainable remediation and desalination practices.

2.3.5 Medicinal and Pharmaceutical Uses

Many halophytes possess bioactive compounds with significant pharmaceutical potential, making them valuable in traditional medicine, pharmacology, cosmetology, and agricultural pesticide production. Ksouri *et al.* (2012) reviewed some nutraceutical and biological properties of halophytes. They stated that some halophytes possess increased amounts of bioactive compounds such as glycosides, polysaccharides, essential oils, sterols, fatty acids, vitamins, phenolic compounds, and carotenoids. As a result, these halophytes have antimicrobial, antioxidant, anti-tumoral, and anti-inflammatory qualities, making them suitable for preventing and treating diseases such as chronic inflammation, cancer, and cardiovascular disorders.

Aderibigbe *et al.* (2022) studied the properties of *Amaranthus spp.* and revealed that the plant possesses rich nutrients and bioactive compounds which improve human and animal health. Another research study by Jimoh *et al.* (2019) emphasized the medicinal qualities of *Amaranthus caudatus* and its use in the treatment of diseases such as cancer, diabetes, malaria inflammations, and other bacterial infections. Also, studies by Vasconcellos *et al.* (2005) and Duke (2008) revealed that *Capraria biflora* is medicinal and used to treat hypertension, menstrual pain, fever, and diarrhoea. The antioxidant properties of *Clitoria ternatea* have been exploited, and the flowers are usually used to make herbal tea, as Suarna and Wijaya (2021) reported. *Euphorbia albomarginata* has also been identified by

Digitized by Sam Jonah Library

Rojas *et al.* (2010) as a medicinal plant useful in traditional medicine for treating various ailments. Mouafon *et al.* (2021) recognized the medicinal qualities of *Indigofera spicata* and stated that the plant contains secondary metabolites, such as flavonoids and saponins, which aid in treating bacterial infections.

Navarrete *et al.* (2021) also investigated the potential of *Kalanchoe daigremontiana*, a succulent halophyte of the Crassulaceae family, in the treatment of diabetes and found that crude leaf extracts from the plant were effective in reducing liver damage under increased sucrose conditions. Another research by Sahayaraj and Sathyamoorthi (2010) revealed that the root extracts of *Pedalium murex* effectively controlled the larvae of tobacco cutworms and can therefore be used as an alternative to synthetic insecticides. Also, Tripathi *et al.* (2021) discovered that the plant is effective in curing illnesses such as reproductive disorders and urinary and gastrointestinal tract disorders.

It is necessary to note that although most of these halophytes possess medicinal qualities, their use has only been exploited locally, with very little research being conducted to confirm the presence of pharmaceutical compounds in them. The identification of novel compounds and further investigations to explore the therapeutic properties of other halophytes are necessary to harness the full potential of halophytes for medicinal purposes.

2.4 Causes of Soil Salinity

Salinity, a prominent form of abiotic stress alongside irradiation, drought, and heavy metal toxicity, exerts profound and detrimental effects on crop

Digitized by Sam Jonah Library

production. The impact of salt stress is particularly pronounced in arid, semi-arid, and coastal regions, where it easily proliferates in irrigated fields (Munns and Tester, 2008). Soil salinity poses significant challenges to agricultural productivity and ecosystem health. The causes of soil salinity are reviewed in this section.

2.4.1 Natural Causes

Natural processes, such as the weathering of parent material, topographical features, and the quality of the water table, account for the basic salinization and sodification of soils. Weathering of primary minerals involves the production of soluble cations like Mg^{2+}, Na^{+}, Ca^{2+}, and $K^{+,}$ as well as prevalent anions such as SO_4^{2-}, HCO^{3-} and Cl^{-} (Stavi *et al.*, 2021). Rocks and minerals exhibit differential susceptibility to chemical weathering, facilitating the release of cations and anions (Sverdrup and Warfvinge, 1988). Studies by Rhoades (1996) and Qadir *et al.* (2014) emphasize the role of geological and climatic factors in determining the baseline salinity levels of soils. Litalien and Zeeb (2020) and Forkutsa *et al.* (2009) highlight the role of agricultural activities such as irrigation and chemical fertilizers in accelerating the natural processes of soil salinization. Other research studies by Ivushkin *et al.* (2019) and Shrivastava and Rajesh (2015) report on the significant impact of the progress of salinization of arable lands on agricultural production and ecological sustainability and highlight the process of natural salinization in soils. Also, according to Cuevas *et al.* (2019), climate change results in increased frequency and intensity of drought occurrences, which contribute significantly to the rate of soil salinization in both arid and humid regions. Rodríguez-Rodríguez *et*

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

al. (1993) also found that volcanic activities, such as ashes blown from sodium-rich minerals during volcanic eruptions, contribute to the salinization of soils.

2.4.2 Human Causes

Another form of soil salinization arises predominantly from inadequate leaching and drainage during water logging or irrigation practices. These circumstances lead to the retention of soluble salts within the soil profile or at the surface. Ayers and Westcot (1985) reported that unless adequately washed away, these salts, over time, accumulate to levels that hinder optimal plant growth. A review by Tedeschi *et al.* (2023) underscores the impact of improper irrigation management on soil salinity. The constant use of saline water for irrigation, and inadequate drainage systems lead to salt accumulation in the soil.

Also, deforestation and land use changes contribute to soil salinity through altered hydrological cycles and increased erosion. Studies by Thiam *et al.* (2021) and Nosetto *et al.* (2013) highlight the links between land-use changes and soil salinization and demonstrate that the destruction of vegetation plays a significant role in creating soil salinity. Thiam *et al.* (2021) found that vegetated areas had significantly lower salt content than non-vegetated areas. They concluded the need to regenerate salt-resistant tree species such as *Acacia sp.* and *Eucalyptus sp.* to restore such non-vegetated areas. Again, industrial activities and urbanization contribute to soil salinity by discharging saline effluents and de-icing salts. Furthermore, Sial *et al.* (2006) study the effects of effluents from chemical, pharmaceutical, and textile industries on the environment and emphasize proper

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

treatment before they are used for irrigation as they are toxic to soil, plants, and animals.

Soil salinity is seen here to be affected by both natural processes and human activities. While there is a considerable body of knowledge on the causes of soil salinity, gaps persist in understanding the interactions between various factors and the potential of specific halophytes in mitigating salinity.

2.5 Methods of Remediating Saline Soils

2.5.1 Phytoremediation

Using salt-tolerant plants has emerged as a promising approach for remediating saline soils and has received some attention. Flowers and Colmer (2008) and Rozema *et al.* (2015) highlight the potential of halophytes, including *Salicornia spp.*, *Atriplex spp.* and *Beta spp.,* in accumulating and excluding salts from the soil. These plants can remove salt from the soil, thereby reducing the salt in the soil. Kushiev *et al.* (2005) studied the remediation ability of the perennial shrub licorice (*Glycyrrhiza glabra*), on a salt-affected field. The plant was cultivated for five years, after which the same field was cultivated with wheat and cotton, resulting in a staggering 278% and 609% increase in yield, respectively. The increase in yield was attributed to increased soil organic carbon content and leaching of salts, demonstrating the dynamic ability of plants to restore degraded soils, making them suitable for crop production.

Notably, phytoremediation represents an economically viable means of soil remediation. Moreover, it aligns with environmentally sustainable practices by

Digitized by Sam Jonah Library

circumventing the use of synthetic chemicals and simultaneously enhancing carbon sequestration (Paz *et al.,* 2020).

2.5.2 Bioremediation and Microbial Interventions

Bioremediation, which involves using microorganisms to break down environmental pollutants, such as salts, has gained attention in recent years. Research by Sun *et al.* (2022) demonstrated that freezing saline water irrigation, which is an economical technique for saline soil amelioration, can reshape the soil microbiome in coastal saline soils, potentially contributing to soil desalination. Another investigation revealed the potential of microbial-derived compounds, including volatile organic compounds, thuricin17, phytohormones and lipochitooligosaccharides in mitigating the effects of salinity stress in crops, thereby indicating the ability of these compounds to address the problems of soil salinity (Naamala and Smith, 2021). Also, Kumawat *et al.* (2022) reviewed the significance of bioremediation in addressing soil salinity. They concluded that microbial products which contain beneficial halophiles can maintain and improve soil health while enhancing crop yield in saline soils. Mokrani *et al.* (2022) discussed recent trends in microbial approaches for soil desalination. They emphasized the impact of global climate change on soil salinization and the potential of bio-phytoremediation by microorganisms in addressing the issue. Microbes, including *Actinobacteria*, *Bacteroidetes, Proteobacteria*, *Spirochaetes*, *Firmicutes,* and *Euryarchaeota* have been identified to possess salt-resistant qualities (Grover *et al.*, 2011). Overall, these studies support the potential of microbial interventions in remediating saline soils. However, gabs exist to

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

understand the long-term effects of microbial interventions on soil health and biodiversity.

2.5.3 Soil Amendments

Adding amendments, such as gypsum, organic matter and calcium-based compounds, has been widely explored to improve soil structure and reduce salinity. Hoque *et al.* (2022) reviewed the role of soil amendments, including vermiwash, biochar, plant growth-promoting rhizobacteria, vermicompost and biofertilizers in mitigating the effects of soil salinity on plant growth. They concluded that these soil amendments significantly reduced the negative effects of soil salinity on crops and promoted plant growth and yield through several mechanisms, such as improving the activities of antioxidant enzymes, maintaining ionic homeostasis, regulating gene expression and reducing osmotic and oxidative stresses. Research by Wang *et al.* (2023) emphasized the effectiveness of humic acid, amino acids and carboxymethyl cellulose as soil amendments in the management of degraded soils and reported on the ability of these amendments to enhance yields and enrich the infiltration characteristics of saline soils. Other amendments, including gypsum, have reportedly been used in the reduction of soil pH and sodium adsorption ratio (SAR), thereby improving soil permeability, nutrient cycling, water holding capacity and enzymatic activities and mitigating effects of soil salinity on soils (Bello *et al.*, 2021). However, these amendments' effects are usually short-lived, requiring continuous and repeated applications, which could have negative environmental effects.

Digitized by Sam Jonah Library

2.5.4 Precision Irrigation Techniques

Innovative irrigation techniques, such as controlled deficit and drip irrigations, have been investigated to manage soil salinity. Plaut *et al.* (2013) found that combining controlled deficit irrigation with other strategies, such as leaching, is effective for overcoming salinity in highly saline soils. Research has also shown that drip irrigation can help control soil salinity under various crops, such as tomatoes, cauliflower, onion and strawberries, by effectively distributing water and leaching salts from the root zone (Burt and Isbell, 2005; Karaca *et al.*, 2022). Also, research by Wang *et al.* (2023) demonstrated that drip irrigation treatments can lead to significant reductions in soil salinity, with desalination rates ranging from 18.46% to 22.94%. When combined with proper water management practices, drip irrigation effectively prevents salt accumulation in the root zone (Plaut *et al.*, 2013). Drip and controlled deficit irrigations, therefore, are valuable tools for managing soil salinity and ensuring the healthy growth of crops in salt-affected areas. However, criticisms revolve around the applicability of these techniques to different crops and regions.

2.5.5 Flushing and Leaching of Salt

Flushing involves washing away the surface accumulated salts by flushing water over the surface, while leaching is the most effective method for removing salts from the root zone of soils. Research by Shaygan and Baumgartl (2022) emphasized the significant role of rainfall and irrigation water in leaching soluble salts from the soil profile. Again, research by Cuevas *et al.* (2019) highlighted the need for improved drainage, less fertilizer application, reduced evaporation,

Digitized by Sam Jonah Library

irrigation with low EC water and high-frequency localized irrigation as mechanisms for reducing salt accumulation is soils and improving soil structure. Another investigation stressed the need to direct the salts flushed from the soil surface into drainage systems to effectively eliminate them from the marked land (Shahid *et al.,* 2018). However, the issue with this method is that the process is often very laborious and expensive and tends to yield short-lived results in reducing soil salinity.

2.5.6 Combined Approaches and Integrative Strategies

Several studies advocate for a holistic approach that combines different remediation methods to address the complex nature of saline soils. This approach recognizes the importance of considering the soil's physical, chemical, and biological properties when designing remediation strategies. Combining biological, chemical, and physical processes is a comprehensive method to mitigate soil salinity (Jakhar *et al.*, 2024). Rezapour *et al.* (2023) found that combining chemical and organic treatments can enhance remediation performance and soil health in saline-sodic soils. Freezing saline water irrigation and plastic mulching techniques were found to reshape the soil microbiome in coastal saline soils and enhance soil desalination (Sun *et al.*, 2022). Another research by Aparicio *et al.* (2022) reported that integrating biological and physicochemical strategies effectively addresses soil salinity problems. Cuevas *et al.* (2019) found that soil salinity can be significantly reduced while crop yields increase by combining soil amendments, residue management and soil conditioners. Integrating halophytes, amendments, and innovative agricultural practices could enhance the overall effectiveness of soil

Digitized by Sam Jonah Library

remediation efforts. However, critical assessments are needed to identify potential conflicts and synergies between different approaches.

2.7 Salinity Effects on Crops

Salinity stress exerts a wide range of effects on crops, including reducing crop productivity and altering soil physicochemical properties. This ultimately disrupts the ecological equilibrium of the region (Hu and Schmidhalter, 2002). Soil salinity results in decreased crop yields, reduced economic returns, and the emergence of soil erosion concerns. The consequences of salinity stress arise from multifaceted interactions, including biochemical, physiological, morphological and molecular processes (Singh and Chatrath, 2001; Akbarimoghaddam *et al.,* 2011; Tester and Davenport, 2003). The effects of soil salinity on crop life cycle and growth have been reviewed in this section.

2.7.1 Effects of Salinity on Crop Life Cycle

Salinity stress extends its influence across various aspects of plant development, leaving no phase untouched, from germination to vegetative growth and reproductive maturation. Soil salinity introduces complex challenges, including ion toxicity, oxidative and osmotic stresses, and deficiencies in crucial nutrients such as nitrogen, calcium, potassium, phosphorus, iron, and zinc (Ashraf, 2004).

Soil salinity has been shown to affect seed germination and early seedling growth adversely. Research has demonstrated that temperature and salinity significantly affect plant species' seed germination percentage and germination rate (Liu *et al.*, 2021). Also, Almansouri *et al.* (2001) and Kranner *et al.* (2010) reported

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

that exposure to high soil salinity inhibits seed germination due to the low osmotic potential created around the seed, which prevents water uptake and the high concentration of sodium and chloride ions in the soil may be toxic to seeds. Another study stressed the role of salinity in lowering the water potential of the germination medium compared to the seed interior, creating an osmotic stress resulting in decreased germination rate and extended germination time (Reguera *et al.*, 2020). High soil salinity can, therefore, have detrimental effects on the germination and early seedling growth of various plant species, resulting in decreased plant performance.

Also, salinity adversely affects vegetative growth, reducing leaf area, stunted growth and altered morphology. Soil salinity has been reported by Kumar *et al.* (2021) to lead to reduced plant height, root length, stem length, number of branches and leaves, affecting the overall growth and biomass of Dropwort (*Oenanthe javanica*) cultivars.

The effects of salinity on reproductive development and crop yield have been extensively studied. According to Uchiyama *et al.* (2023), salinity hinders microsporogenesis, impedes the elongation of stamen filament, triggers ovule abortion, prompts the senescence of fertilized embryos and induces programmed cell death in select tissues. Also, high soil salinity has been found to reduce crop yields and yield components, resulting in yield loss in various crop species, including beans, tomatoes and cabbage (Atta *et al.*, 2023). Salinity has been reported by Shrivastava and Kumar (2015) to adversely affect reproductive development by inhibiting microsporogenesis and stamen, enhancing programmed

Digitized by Sam Jonah Library

cell death in some tissue types, ovule abortion and senescence of fertilized embryos. In vitro, pollen viability and germination tests from petunia, maize and carrot plants grown under saline conditions have demonstrated that high soil salinity inhibits plant growth and reduces pollen viability (Mattioli *et al.*, 2020). Also, Pushpavalli *et al.* (2016) reported that salinity stress can lead to delayed flowering and lower crop yield. Therefore, high salt concentrations can harm pollen viability and flower development and crop yield.

It is important to note that most of these studies focus on major crops, such as wheat and maize, with less attention to other important crops. More research is needed to explore the adaptability of various crops to varying salinity levels.

2.7.2 Effects of Salinity on Growth Parameters

2.7.2.1 Plant Height

Salinity stress significantly threatens plant growth and development, affecting various physiological and morphological aspects, including plant height. The impact of salinity stress on plant height has been extensively studied, and the degree of growth reduction varies among plant species. Research has demonstrated that high soil salinity can significantly reduce plant height, root length, stem length and the number of branches and leaves in various plant species (Kumar *et al.*, 2021; Balasubramaniam *et al.*, 2023). Another investigation by Shrivastava and Kumar (2015) highlighted the effect of salinity on all aspects of plant development, imposing osmotic stress, oxidative stress, ion toxicity and nutrient imbalance on plants, which can lead to reduced plant height and overall growth. Saline soils were shown to negatively influence plant height in asparagus and tomato (Jumberi *et al.,*

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

2002). Similarly, another study on the effect of salinity stress on rice crops by Hasanuzzaman *et al.* (2009) showed that rice crops exposed to rising salinity levels in the soil demonstrated a reduction in plant height. This trend extends to pepper plants, where increased soil salt content resulted in a noticeable decrease in plant height (Hussein *et al.,* 2012; Sakr *et al.,* 2015).

While significant progress has been made in the study of the impact of soil salinity on plant height, the diversity of plants studied remains a major constraint. Future research should prioritize a broader range of plants and environments to address these gaps.

2.7.2.2 Root Parameters

Salinity stress significantly influences plant root morphology and physiology. The structure of roots, including root diameter and length, influences both water uptake and nutrient uptake within saline soils (Schleiff, 2008; Acosta-Motos *et al.,* 2017). Robin *et al.* (2016) studied the effects of soil salinity on wheat plants. They found that salinity stress reduces root surface area, root hair density, and root hair length, leading to changes in major root and shoot traits at the phytomer level. Another research by Arif *et al.* (2019) demonstrated that salinity affects root system architecture and expansion of *Brassica napus,* and root processes are affected differently by excess salinity. Khan *et al.* (2003), Nizam (2011), and Dolatabadian *et al.* (2011) reported reduced root length in maize, ryegrass and soybean, respectively. It has also been reported that salt stress significantly limited root density in pepper (De Pascale *et al.,* 2003).

Digitized by Sam Jonah Library

2.7.2.3 Leaf Parameters

Several studies have explored the effect of soil salinity on leaf parameters. Research has shown that salinity stress can modify tomato plants' leaf anatomy and gene expression patterns (Hoffmann *et al.*, 2021). Salinity stress has been found to reduce leaf area, chlorophyll content and stomatal conductance (Negrão *et al.*, 2017; Balasubramaniam *et al.*, 2023). Negrão *et al.* (2017) again found that salinity stress affects cell expansion in young leaves, generally causing a decrease in leaf area. Srivastava (2022) reviewed the adaptations of plants to salinity and concluded that elevated levels of soil salinity result in increased leaf area and stomata and trichomes numbers and sizes considered adaptive traits against salinity stress. Also, in mustard plants, leaf area was significantly reduced at vegetative and reproductive stages due to salt stress (Garg *et al.,* 2006). Similar occurrences were observed in tomatoes, sugar beet, cabbage and bitter almonds (Romero-Aranda *et al.,* 2001; Jamil *et al.,* 2007; Najafian *et al.,* 2008). Hasanuzzaman *et al.* (2013) also highlighted the decrease in the number of leaves. They attributed this to osmotic influence, which, in extreme cases, can lead to leaf death, ultimately compromising the plant's photosynthetic capacity and consequent yield.

2.7.2.4 Biomass Accumulation

Biomass accumulation is a key determinant of plant productivity, and understanding how salinity stress influences this parameter is crucial for sustainable agriculture. Studies have investigated the impact of salinity stress on shoot and root biomass accumulation. It has been reported that overall crop yield is affected under

Digitized by Sam Jonah Library

salt stress due to reduced leaf area, which eventually results in reduced dry matter accumulation (Amirjani, 2011). For instance, it was observed that shoot dry biomass was significantly reduced in mustard plants where saline water at varying concentrations was used for irrigation (Garg *et al.,* 2006). In pepper, using irrigation water with electrical conductivities of 4.4 dS/m and 8.5 dS/m resulted in reduced leaf and stem weights (De Pascal *et al.,* 2003).

Similarly, Yildirim and Güvenç (2006) reported declining shoot and root biomass in pepper under increasing saline treatments. These reductions in biomass accumulation have often been attributed to hindered water and nutrient uptake, oxidative stress and metabolic disturbances (Munns and Gilliham, 2015; Flowers and Colmer, 2008). However, another study found a 10 – 20% increase in seedling growth (both root and shoot biomass) of *Brassica napus* when treated with moderately saline solutions (between 25 and 50 mmol L^{-1} NaCl) (Chen *et al.*, 2023). Salinity was reported to reduce common beans' shoot and root weights (Gama *et al.*, 2007). On the other hand, research by Maggio *et al.* (2007) and Tejera *et al.* (2006) found that salinity significantly increased root biomass in tomatoes and chickpeas, suggesting a faster root growth to adjust to water deficit. Another investigation showed that, although salinity stress reduced biomass production and productivity in soybeans, adding biochar decreases these negative effects of salinity on the plant (Zhang *et al.*, 2020).

Furthermore, Alam *et al.* (2015) studied the effect of salinity on the biomass yield of purslane accessions. They found that high salt treatments resulted in a significant decrease in both fresh and dry weights of the accessions. Likewise, the

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

biomass of sugar beet cultivars decreased significantly with increasing salinity stress (Dadkhah and Grrifiths, 2006). Contrary to this, according to Mane *et al.* (2011), 100mM salinity led to a significant increase in fresh mass of *Pennisetum alopecuroides*.

Overall, the study of the effects of salinity on plant growth parameters has received some attention. However, more remains to be done to study the growth of beneficial halophytes under salt stress conditions. Halophytes remain a viable source of mitigating salinity's effects on glycophytes' growth.

2.7.3 Effects of Salinity on Physiological Parameters

To assess the tolerance of plants under salinity stress, researchers commonly evaluate either the growth or survival of the plant, as these metrics summarize the relationship of numerous physiological mechanisms within the plant. Salinity has been reported to impact the process of photosynthesis, primarily by reducing chlorophyll content, leaf area and stomatal conductance. Research has found that, although minimally, salinity decreases photosystem II's efficiency, reducing the overall photosynthesis efficiency in plants (Netondo *et al.,* 2004). The effects of salinity stress on various physiological processes in plants are discussed in this section.

2.7.3.1 Chlorophyll content

Salt stress is known to have a profound impact on plant physiology, particularly on chlorophyll content. Under salt stress, the chlorophyll pigment, pivotal in photosynthesis, encounters significant inhibition. Salinity stress has been

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

found to reduce chlorophyll content in maize plants' leaves, leading to decreased pigment synthesis or a high rate of chlorophyll degradation (Ashrafuzzaman *et al.*, 2000). Hnilickova *et al.* (2021) investigated the effects of salinity on *Portulaca oleracea*. They found that salinity stress affected photosynthesis, mainly through a reduction in leaf area, stomatal conductance and chlorophyll content, which ultimately impacts the overall growth and biomass of the plants.

Furthermore, the chlorophyll a and b content in paddy rice under saline treatment has been studied, indicating that salinity stress reduces the chlorophyll a and b content in rice varieties, eventually reducing plant biomass (Taratima *et al.*, 2022). Another study by Heidari (2012) found that high salinity levels greatly reduced photosynthetic pigments, particularly chlorophylls a and b and carotenoid contents of basil genotypes. Also, according to Jaleel *et al.* (2008), total chlorophyll and chlorophylls a and b contents were slightly decreased at low salinity concentrations. However, these pigments were significantly reduced in *Catharanthus roseus* plants at high salt concentrations. Another study on salt-tolerant and sensitive pepper varieties revealed that salt treatments reduced leaf chlorophyll content of the salt-sensitive variety at low salt concentrations (50 mM NaCl). The salt-tolerant variety had reduced leaf chlorophyll content at a relatively higher salt concentration (200 mM NaCl) (Hand *et al.*, 2017). Furthermore, the application of sodium chloride correlated with a decrease in chlorophyll levels in maize (Sepehr and Ghorbanli, 2006), rice (Lutts *et al.,* 1996) and pearl millet (Albassam, 2001). These results indicate that salinity stress harms chlorophyll

Digitized by Sam Jonah Library

content in plants, which can affect their photosynthetic efficiency and overall growth.

2.7.3.2 Fv/Fm Ratio

The fv/fm ratio measures the maximum efficiency of photosystem II photochemistry. The effects of salinity on the fv/fm ratio have been studied in various plant species. For instance, a study on wheat under saline conditions demonstrated a marked reduction in the fv/fm ratio due to reduced photochemical efficiency (Saddiq *et al.,* 2021). Salt-stressed tomato plants also displayed lowered fv/fm values, signifying compromised photosynthetic activity and potential damage to PSII (Nabati *et al.,* 2021). Also, a study on *Portulaca oleracea* by Hnilickova *et al.* (2021) found that salt stress significantly reduced the fv/fm ratio after 12 days of exposure to 300 mM NaCl. Similarly, research on grafted watermelon seedlings demonstrated decreased fv/fm values under salinity stress, especially at higher salinity levels (Shin *et al.*, 2021). Furthermore, a study on lettuce exposed to salinity stress reported a reduction in the fv/fm ratio, indicating the negative impact of salinity stress on photosystem II photochemistry (Adhikari *et al.*, 2019). Again, salinity stress has been found to affect chloroplast structure and function, reducing CO2 assimilation rates and overreduction photosystem II (Hameed *et al.*, 2021). Studies on salt-stressed *Arabidopsis thaliana* emphasized that the fv/fm ratio can indicate stress-induced damage to the photosynthetic apparatus (Othman *et al.,* 2017). The fv/fm ratio is very sensitive to salt stress and is, therefore, usually used to assess the response of various plants to salt stress.

Digitized by Sam Jonah Library

2.7.3.3 Performance Index (PI)

The performance index combines several chlorophyll fluorescence measurements such as Fv/Fm and Fv'/Fm' to assess the overall photosynthetic efficiency of plants under stress. The effects of salinity on the Performance Index have been studied in various plant species. For example, a study on rice subjected to salt stress revealed reduced PI values due to compromised photosystem functionality and electron transport rates (Giorio and Sellami, 2021). Similarly, investigations on wheat highlighted the negative impact of salt stress on the PI, indicating hampered photosynthetic performance and potential cellular damage (Saddiq *et al.,* 2021). Another study on safflower showed that salt stress caused a significant decrease in maximum fluorescence (Fm) and PItotal. At the same time, the energy necessary for the closure of all reaction centres (Sm) increased (Ghassemi-Golezani *et al.,* 2020). Furthermore, the exogenous application of melatonin induced tolerance to salt stress by improving the photosynthetic efficiency and antioxidant defence system of maize seedlings (Ahmad *et al.,* 2020).

2.8 Salt Tolerance in Halophytes

In light of the adverse effects of salinity on crops, understanding the tolerance mechanism of halophytes becomes crucial for enhancing crop plants' stress resilience. Several studies have investigated various aspects of salt tolerance in halophytes, including their ability to complete their lifecycle in saline conditions, the mechanisms underlying their salt tolerance, and their potential as valuable genetic resources for developing salt-tolerant crops. These studies have provided valuable insights into the unique anatomical, physiological and morphological

Digitized by Sam Jonah Library

strategies that halophytes have evolved to survive and thrive in saline environments. This review delves into various aspects of halophytes, focusing on their tolerance mechanisms to salinity.

While some halophytes have developed resistance mechanisms, others employ strategies to avoid salt uptake actively, thereby maintaining a lower internal sodium concentration. These mechanisms collectively enable them to maintain cellular functions, sustain growth, and thrive in saline conditions (Flowers and Colmer, 2008).

2.8.1 Mechanisms of Salt Resistance in Halophytes

Salt resistance is the ability of plants to tolerate high salt concentrations in their environment. This salt tolerance mechanism usually involves maintaining protoplasmic viability through biochemical and physiological adaptations (Sabovljevic and Sabovljevic, 2007). Halophytes have evolved various mechanisms to cope with salinity stress, allowing them to complete their life cycles in soils with high salt concentrations (Meng *et al.*, 2018). The mechanisms of salt resistance are reviewed below.

2.8.1.1 Osmotic Adjustment

Some salt-resistant halophytes accumulate organic and inorganic osmoprotectants as well as compatible solutes, such as proline, glycine betaine, and sugars, in their cells to maintain turgor pressure and water uptake in their cells and stabilize essential cellular structures to counter the osmotic stress induced by high external salinity (Kefu and Hai, 2000; Flowers and Colmer, 2008). For instance,

Digitized by Sam Jonah Library

Stewart and Lee (1974) highlighted the positive correlation between proline accumulation and salt tolerance in *Armeria maritima*. Also, another investigation found that the accumulation of proline served as a source of solute for intracellular osmotic adjustments in halophytes (Hmidi *et al.*, 2018).

Studies on the role of proline in salt stress tolerance revealed that exogenous application of proline significantly enhanced salt tolerance in different plants, including *A. thaliana*, *Z. mays*, and *Triticum aestivum* (Székely *et al.*, 2008; de Freitas *et al.*, 2018; Rady *et al.*, 2019; El Moukhtari *et al.*, 2020). Again, research on *Urochondra setulose* and *M. crystallinum* demonstrated that the increased proline accumulation and expression of genes responsible for proline synthesis enhanced salt tolerance under stress conditions (Tran *et al.*, 2019; Mann *et al.*, 2021). Also, studies by Slama *et al.* (2015) emphasized the roles of solutes such as glycine betaine and sugars in maintaining cellular osmotic balance in plants such as *Limonium latifolium*, *Atriplex halimus*, *Kochia sieversiana*, *Suaeda fruticose*, *Salicornia europaea*, *C. quinoa* and *Noaea mucronate* as well as other plants belonging to the Amaranthaceae family. Glycine betaine has again been identified to enhance salt tolerance in *Sesuvium portulacastrum* (Muchate *et al.*, 2016) and *triplex halimus* (Hamdani *et al.*, 2017).

2.8.1.2 Antioxidant Defense

Certain halophytes also possess robust antioxidant defence systems to counteract the oxidative stress of salt-induced reactive oxygen species (ROS) (Bose *et al.,* 2014). This includes the upregulation of enzymes like superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) to detoxify ROS and protect cellular

Digitized by Sam Jonah Library

components from oxidative damage. A study on the halophyte *Salvadora persica* demonstrated that the constitutive levels of all the antioxidative enzymes (that is, SOD, CAT, ascorbate peroxidase (APX) and peroxidase (POX)) in the halophyte were much higher than those reported in glycophytes, indicating the importance of these enzymes in salt tolerance (Rangani *et al.*, 2016). Also, the role of ROS detoxification as an important biochemical mechanism has been identified in *H. salicornicum* where under salinity stress, AsA/dehydroascorbate (DHA) and glutathione (GSH)/oxidized glutathione (GSSG) ratios increased, the activity of SOD increased and the levels of glutathione (GSH) increased (Panda *et al.*, 2019). Enhanced abscisic acid (ABA) levels have also been reported to enhance salt tolerance in *S. persica*, *A. tripolium* and *Lycium humile*, through the reduction of oxidative stresses in these plants (Kumari and Parida, 2018; Wiszniewska *et al.*, 2021; Palchett *et al.*, 2021).

2.8.1.3 Ion Homeostasis

Another key strategy employed by salt-resistant halophytes is ion homeostasis. These plants have evolved specialized transporters and ion channels in their root systems to selectively exclude sodium ions (Na^+) from entering the plant's vascular system (Munns, 2005; Levitt, 1980). For example, the *Suaeda salsa* halophyte employs a high-affinity potassium transporter (HKT1) that allows it to preferentially take up potassium (K^+) over sodium (Na^+), thus maintaining a low Na^+/K^+ ratio within its cells (Shao *et al.,* 2014). Also, it was observed that, under salinity stress, *Nitraria sibirica* plants sequestered Na^+ in their vacuoles, thereby keeping an ideal balance of K^+/Na^+ at the cell-specific and tissue-specific levels

Digitized by Sam Jonah Library

(Tang *et al.*, 2020). Again, the *Nitraria sibirica* plants were found to promote the efflux of K^+ from their vacuoles to their cytoplasm through the enhanced expression of two-pore K^+ (NsTPK) (Tang *et al.*, 2020). Also, salt overly sensitive (SOS) has been reported to aid salt tolerance in *Lobularia maritima* (Ben *et al.*, 2020), *Karelinia caspia* (Guo *et al.*, 2020), *Cakile maritima* (Arbelet-Bonnin *et al.*, 2018) and *Pongamia pinnata* (Marriboina *et al.*, 2017) through Na^+ exclusion, Ca^{2+} signaling, and sequestration of excess Na^+, resulting in increased ion homeostasis.

2.8.1.4 Stomatal Conductance

Stomata conductance plays a role in salt resistance by regulating water loss and gas exchange in halophytes, resulting in a low CO_2: O_2 ratio. Halophytes can control stomata aperture and optimize water use efficiency by reducing stomatal density (Suriani and Talanca, 2019; Shabala, 2013). In an investigation, decreased stomatal conductance and density were observed when plants were exposed to salt stress (Gururani *et al.*, 2015). Studies on *Gossypium hirsutum* L. and *Phaseolus vulgaris* L. revealed that both plants exhibited reduced O_2 evolution and CO_2 uptake as a stomatal mechanism of response to salt stress (Brugnoli and Lauteri, 1991). The study also concluded that the reduced stomatal conductance was responsible for the decreased assimilation rate in these plants (Brugnoli and Lauteri, 1991). Also, it has been revealed that abscisic acid (ABA) accumulation was responsible for reducing stomatal conductance in plants (Sharipova *et al.*, 2022). A study on Barley demonstrated that salinity stress induced ABA production, resulting in reduced plant stomatal conductance (Sharipova *et al.*, 2022). Reduced stomatal conductivity has been observed in *Arabidopsis thaliana* (Orzechowska *et*

Digitized by Sam Jonah Library

al., 2021), tomato (Song *et al.*, 2023) and *Atriplex portulacoides* (Redondo-Gómez *et al.*, 2007). Also, studies have shown that some halophytes, including *Suaeda maritima* (Flowers, 1985), *Lasiurus scindicus* (Naz *et al.*, 2010), *Distichlis spicata* (Kemp and Cunningham, 1981), *Aeloropus lagopodies* (Naz *et al.*, 2010), and *Chenopodium quinoa* (Orsini *et al.*, 2011) exhibit reduced stomatal density in response to salt stress.

2.8.2 Mechanisms of Salt Avoidance in Halophytes

Salt avoidance involves keeping sensitive parts of the plant free from salt ions. This mechanism is more common in glycophytes and minimises the plant's salt uptake.

2.8.2.1 Salt Compartmentalization

Salt compartmentalization is one of the salt tolerance mechanisms that halophytes use to tolerate high salt concentrations. These halophytes avoid salt stress by reducing the salt concentration in their cytoplasm by compartmentalizing the salt in their vacuoles (Munns, 2002; Larcher, 2003). A study on the salinity tolerance of upland cotton (*Gossypium hirsutum*) identified the secretion of salt from glandular trichomes (GTs) as a mechanism of Na^+ compartmentalization in the plants after short-term salt stress was applied (Peng *et al.*, 2016). According to Sulian *et al.* (2012), who studied the mechanism of salt tolerance in *Salicornia europaea*, the plants could tolerate salt stress through multiple compartmentalization of Na^+ in the vacuoles. Also, Lv *et al.* (2017) researched salt tolerance in *Salicornia europaea*. They found that the plant tolerates salinity stress

Digitized by Sam Jonah Library

by Na^+ compartmentalization in their vacuole and concluded that this mechanism is aided by V-ATPase subunit-A. Another study reported that when *B. gymnorhiza* plants were exposed to increasing concentrations of NaCl, their leaves could avoid the excess production of reactive oxygen species (ROS) due to effective salt compartmentalization in their vacuoles (Li *et al.*, 2018). These mechanisms of salt compartmentalization in halophytes are crucial for their ability to thrive in salt-affected soils.

2.8.2.1 Exclusion

Another primary strategy employed by salt-avoiding halophytes is the exclusion of salt ions. These plants have evolved root membranes with reduced sodium ions (Na+) permeability. This permeability reduction limits salt uptake from the surrounding soil, thereby minimizing the entry of toxic ions into the plant's vascular system (Larcher, 2003). Reed plants were found to accumulate increased concentrations of Na^+ and Cl^- in their roots compared to their shoots when exposed to salt treatment, indicating the exclusion of salts from their roots (Matsushita and Matoh, 1991). Also, Husain *et al.* (2004) studied salt transport in plants and found that most salt-exclusion plants exclude about 98% of salt absorbed by their roots back into the soil solution and only transport 2% to the shoots. The phloem, root cortex and, xylem and pericycle parenchyma cells have been reported as the key sites for salt exclusion in plants that avoid salt stress by salt exclusion (Munns *et al.*, 2006). Research by Chen *et al.* (2018) found that salt-excluders are mostly monocotyledonous plants and emphasized the need to understand this mechanism of salt avoidance in the improvement of monocotyledonous crops including rice,

Digitized by Sam Jonah Library

sorghum, wheat and maize. Another investigation by Li *et al.* (2018) concluded that to reduce ROS production in the roots and leaves, *K. obovate* efficiently excludes salt from the roots.

2.8.2.2 Salt Gland Secretion

Certain halophytes have developed specialized salt glands or salt bladders on their leaves or stems, which actively secrete excess salt ions, primarily sodium and chloride (Yuan *et al.,* 2016). These halophytes are called recretohalophytes. Yuan *et al.,* (2016) reviewed the salt secretion mechanism in recretohalophytes. They emphasized the process of salt gland development, highlighting the role of ion transporters in the secretion of ions from the salt bladders of halophytes. Another study on salt tolerance in *Avicennia marina* focused on the plant's salt gland-mediated leaf sodium homeostasis and its role in conferring salt tolerance on the plant (Guo *et al.*, 2023). *Tamarix aphylla* and *Bienertia sinuspersici* have also been reported to possess salt glands which aid them in the secretion of excess salt from their tissues (Akhani *et al.*, 2005).

Studies have shown that the mechanism of salt secretion in recretohalophytes depends on their salt glands' structure. Dassanayake and Larkin (2017) reported that, *Porteresia coarctata*, a wild rice species, possessed unicellular secretory hairs, which seemed to be wholly occupied with vacuoles and no specialized organelles. Also, bicellular salt glands (cap and basal cells) were found in *Chloridoid* grasses (Amarasinghe and Watson, 1988). Again, a study on *Limonium bicolor* also demonstrated that the plant possessed multiple-celled salt

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

glands and accumulated salt crystals around pores found in their secretory cells, indicating the mechanism of salt excretion from the plant (Feng *et al.*, 2014). *Amaranthaceae* (including *Suaeda aralocaspica* and *Bienertia sinuspersici*) and *Aizoaceae* (such as *M. crystallinum*) have also been reported to sequester salt in their bladder cell vacuoles, making them salt bladders (Park *et al.*, 2009; Agarie *et al.*, 2007). Therefore, four (4) mechanisms of salt secretion have been identified based on the structure of salt glands.

2.8.2.3 Succulence

Succulence is a salt tolerance mechanism that has been studied in various halophytes. Succulence refers to the thickening of leaves and stems, which help these plants store water and ions and cope with salinity stress. Succulent halophytes have been shown to store water in their leaves, stems, and roots, which dilutes the salt concentration in their tissues (Flowers and Colmer, 2008; Mann *et al.*, 2018). For example, a study by Vyas *et al.* (2023) found that the succulent halophytes, *Suaeda nudiflora*, *Suaeda fruticose* and *Salicornia brachiate* have thick and fleshy leaves, which enable them to store water and ions and exhibit salt avoidance mechanism while non-succulent ones, *Urochondra setulosa* and *Aeluropus lagopoides* exhibit a salt tolerance mechanism. The research emphasized on the ability of the succulent halophytes to accumulate increased Na^+, Mg^{+2} and Cl^- in their leaves than their roots and stems (Vyas *et al.*, 2023). Another study revealed that *Suaeda fruticose* can withstand salt concentrations of 500 and 1000 mM NaCl at germination and maturity due to its succulence (Khan and Ungar, 1998; 2000).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Furthermore, research on succulent halophytes in Egypt revealed that increasing salt concentrations increased succulence in *Zygophyllum aegyptium* and *Halocnemum strobilaceum*. In contrast, *Inula crithmoides* and *Arthrocnemum macrostachyum* exhibited a reduction in succulence at high salinity levels (Serag, 1999). Also, according to Weber, (2009), succulent halophytes usually have higher moisture content per unit area, increased cell size and reduced growth, which help them thrive under saline conditions.

2.8.2.4 Salt Retranslocation and Shedding of Leaves

Another interesting mechanism observed in some salt-avoiding halophytes involves the retranslocation of salt and subsequent shedding of leaves. Such halophytes have been reported to retranslocate Na^+ and Cl^- from active leaves and meristems to older leaves, which they shed off to reduce the salt concentration in their tissues (Flowers and Colmer, 2008, Greenway *et al.,* 1966). Aslam *et al.* (2011) review the significant role of leaf shedding as a mechanism to eliminate excess salts in some halophytes under salt stress. Also, a study by Sáenz-Mata *et al.* (2016) highlighted leaf drop as a mechanism of salt tolerance in some halophytes. Another study on the salt tolerance of *Acacia tortilis* demonstrated that the plant responded to salinity stress by shedding its old leaves (Alhaddad *et al.*, 2021). Furthermore, a study by Mehari *et al.*, (2005) on *Acacia nilotica* and *Acacia tortilis* showed that the plants shed their leaves in the presence of salt stress of 150 and 300 mM to survive the stress conditions.

These salt avoidance and resistance mechanisms in halophytes can be harnessed to develop salt-tolerant crop varieties by transferring these mechanisms

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

to non-halophytic plants such as rice, wheat, and maize. Although salt tolerance mechanisms in plants have received some attention in terms of research, only a few plants have been studied. Future research should focus on other halophytes that have received little attention, especially those in the tropics.

2.9 Salinity Concerns in Ghana

Ghana faces significant challenges related to salinity, with most saline soils concentrated within the country's coastal areas. Specifically, the Accra-Ho-Keta Plains in the Greater Accra and Volta Regions are composed of hydromorphic, highly salty and nutrient-poor soils. Some areas, such as the Agawtaw, even feature impenetrable sodium-saturated pans, which aggravates the unfavourable conditions for crop cultivation (Asamoah *et al*., 2013). The Plains experience an annual rainfall of about 760 mm, which is unreliable and is further worsened by a high evapotranspiration probability, resulting in a significant water-salt imbalance in these areas (FAO, 2000).

In Ghana, the salinity of soils originates primarily from artesian waters, the seas, or natural rocks. Evaporation along the coast transports saline groundwater to the surface through capillary action, leading to soil salinization. The harsh climate further enhances this phenomenon to which the Plains are subjected (Asamoah *et al.,* 2013). Soil salinization occurs due to seawater sprays, invasion, and flooding of plains and low-lying areas. Additionally, soluble sodium salts of silicates, bicarbonates, carbonates, chlorides and sulfates are produced during the weathering of rocks which contain sodium minerals, and these contribute to the elevated amounts of salts in the soils (Pearson and Bauder, 2006; FAO, 2000).

Digitized by Sam Jonah Library

Ghana has considerable areas of Solonchaks (200,000 ha) and Alkaline (118,000 ha) soils, along with Arenosols (70,000 ha) and Solonetzs (600,000 ha) (Szabolcs, 1989; FAO, 2000). The salinity of solonchaks, which originates from marine sources, decreases with depth and spreads from the ocean. They may have a region of sand-like patches composed of a mass of clay, saline-alkali in nature or a weakly formed salt-crust on their surfaces and contain calcium-magnesium complex or sodium cations, together with Chlorine or Sulphur anions (Li *et al.*, 2021).

2.9.1 Methods of Remediating Salinity in Ghana

In Ghana, saline soil management primarily relies on applying organic matter, a general practice (Asamoah *et al.,* 2013). However, the availability of organic residues on saline soils is limited due to competing uses, such as roofing, fuel, livestock feed, and handicrafts, depending on the source (Fosu *et al.,* 2004). Despite its popularity, the application of organic matter has not been entirely successful in curbing the rising salinization of soils in the country. The technique most likely to be adopted must align with the needs of the country's developing economy, where agriculture plays a central role.

Considering the broad needs of Ghanaian industries, such as fuel, forage, fodder, landscaping, ornamentals, mulch, pulp, resins, gums, essential oils, fibre and timber, the use of halophytes appears to be a feasible and beneficial technique for managing saline soils in the country (Le Houérou, 1979; 1985, and 1986; Aronson, 1989; Malcolm and Pol, 1986; O'Leary, 1988; Choukr-Allah, 1997). Halophytes have demonstrated their ability to thrive under highly saline conditions

Digitized by Sam Jonah Library

and offer numerous advantages, including carbon sequestration. Halophytes are a cost-effective, environmentally friendly, and feasible approach. However, careful consideration should be given to selecting halophyte species, whether native or exotic, based on extensive species, site, and farmer-specific research. Endangered halophyte species should be introduced cautiously to avoid potential competition with native species, as the continued existence of native species is crucial for maintaining agro-biodiversity.

While organic matter application remains a widely-used technique, adopting halophytes seems promising for effectively managing Ghanaian saline soils, provided thorough research guides the choice of suitable halophyte species. With the proper implementation of this technique, Ghana can address its salinity concerns and support the growth of its vital agricultural sector.

2.9.2 Halophyte Research in Ghana

In the dynamic landscape of agricultural and environmental research, there is a growing recognition of the significance of halophytes, salt-tolerant plants uniquely adapted to thrive in saline conditions. These plants have emerged as a critical avenue for sustainable land management. However, it is noteworthy that a substantial research gap concerning halophytes exists within the Ghanaian context. To my knowledge, Swaine *et al.* (1979) remains the only article discussing halophyte diversity in Ghana. This illustrates the dearth of research done on halophytes in Ghana. As agriculture continues to be the cornerstone of the nation's economy, addressing the escalating issue of saline soils becomes paramount.

Digitized by Sam Jonah Library

This situation makes investigating halophyte research more than just a scientific endeavour. It also makes it a deliberate effort to use nature-based solutions to improve agricultural resilience and ecological restoration. This research seeks to explore the pivotal role that local halophytes can play in the context of Ghana's agricultural landscape. By highlighting the potential advantages such research could have for Ghana's agricultural industry and environment, it sheds light on the urgent need for fresh research and innovation.

The research work titled "Zonation of a Coastal Grassland in Ghana, West Africa," authored by Swaine *et al.* in 1979, provides an account of the zonation patterns observed in a coastal grassland behind a lagoon in Ghana. The study investigates the relationship between these zonation patterns and the seasonal fluctuations in the ecosystem's moisture content, chlorinity, and aeration. The specific study area is situated in Botianor, located just west of Accra, and covers an area of approximately 0.68 hectares. This site is situated within the transitional zone where the sandy soils gradually reduce, giving way to the emergence of alluvial clays at the surface, making it a particularly interesting area for ecological investigation.

In this research, an inventory of plant species was identified in 1973, which included *Avicennia germinans*, *Sesuvium portulacastrum*, *Paspalum vaginatum*, *Sporobolus robustus*, *Cyperus articulatus*, *Panicum repens*, *Imperata cylindrica*, *Pycreus polystachyos*, *Andropogon gayanus*, *Vernonia cinerea*, *Fimbristylis hispidula*, *Cassia mimosoides*, *Phyllanthus amarus*, *Commelina erecta*, *Oldenlandia corymbose*, *Vigna ambacensis*.

Digitized by Sam Jonah Library

Similarly, in 1974, the survey resulted in the identification of an array of plant species. These included *Andropogon gayanus*, *Hyperthelia dissoluta*, *Fimbristylis hispidula*, *Merremia tridentata*, *Aspilia ciliata*, *Brachiaria falcifera*, *Casia mimosoides*, *Commelina erecta*, *Crotalaria goreensis*, *Galactia tenuiflora*, *Indigofera sp.*, *Pennisetum polystachion*, *Phyllanthus amarus*, *Schwenckia americana*, *Sporobolus pyramidalis*, *Tephrosia linearis*, *Urginea indica*, *Vigna ambacensis*, *Vernonia cinerea*, *Pycreus polystachyos*, *Imperata cylindrica*, *Panicum repens*, *Cyperus articulatus*, *Croton lobatus*, *Exacum quinquenervium*, *Fimbristylis pilosa*, *Oldenlandia corymbosa*, *Paspalum vaginatum*, *Sporobolus robustus*, *Sesuvium portulacastrum*, and *Avicennia germinans*.

2.9.3 Importance and Potential Uses of the Selected Halophytes in Ghana

Halophytic plants have gained increasing attention due to their adaptability to saline environments and potential contributions to various sectors, including agriculture, nutrition, and environmental management. In this section, we study the importance and salinity response of five local halophytes: *Ipomoea aquatica*, *Lactuca taraxacifolia*, *Paspalum vaginatum*, *Sesuvium portulacastrum*, and *Talinum triangulare*.

2.9.3.1 *Ipomoea aquatica* (Water Spinach)

Ipomoea aquatica Forsk., commonly known as water spinach, is an aquatic plant distinguished by its elongated and hollow stems, with numerous air passages and usually having root formations at the nodes. The plant's leaves exhibit an elliptical morphology, with white or pale purple funnel- or cone-shaped flowers

Digitized by Sam Jonah Library

(Edie and Ho 1969; Gamble 1921). Its fruit is capsule-like in structure (Payne, 1956; Synder *et al.,* 1981).

Ipomoea aquatica has a rich nutritional profile and is valued particularly in Southeast Asia (Chen *et al.,* 1991; Candlish *et al.*, 1987). It is a natural source of essential minerals, including vitamins such as A and B (Igwenyi *et al.*, 2011). Additionally, it contains S-methylmethionine, which has been recognized for its potential therapeutic usefulness in gastrointestinal tract (GIT) disorders (Roi, 1955). The plant synthesizes several secondary metabolites, including amino acids, β-carotene, flavonoids, lipids, alkaloids, saponins, steroids, phenols, essential minerals and reducing sugars (Pandjaitan *et al.*, 2005; Bergman *et al.*, 2001).

Traditionally, *I. aquatica* has been applied in the treatment of several ailments, including migraines, constipation, and sleep-related conditions (Burkill 1966); gastrointestinal disorders, diabetes, and mental health issues (Samuelsson *et al.*, 1992) and liver-related ailments (Badruzzaman and Husain, 1992). It has also been reported that it works as a remedy for hypertension and nosebleeds (Perry and Metzger 1980; Duke and Ayensu 1985) and possesses anthelmintic antiepileptic and hypolipidemic properties (Nadkarni 1954; Dhanasekaran and Muralidaran 2010). Moreover, *I. aquatica* has been found to display antimicrobial and anti-inflammatory attributes (Dhanasekaran and Muralidaran 2010) and is believed to inhibit prostaglandin generation (Tseng *et al.*, 1992). In cases of arsenic poisoning, the plant extract is reported to be effective, and poultices derived from it are employed to alleviate itching (Khare 2007).

Digitized by Sam Jonah Library

Ipomoea aquatica typically thrives in moist soils adjacent to stagnant or freshwater bodies or marshy fields, although specific studies on its salt tolerance mechanism are limited. Generally, salinity hinders the germination process and the overall growth and development of plants. A study demonstrated that increasing salinity stress resulted in a gradual decrease in growth and reductions in the osmotic and leaf water potentials and transpiration and photosynthesis rates of *I. aquatica* (Yousif *et al.*, 2010). However, according to Ibrahim *et al.* (2019), although the total flavonoids and phenolic contents, radicle and hypocotyl length, water uptake efficiency and seed vigour of *I. aquatica* were significantly reduced when treated with increasing concentrations of NaCl., the plants exhibited an enhanced salt tolerance response to increasing salinity levels. Another study by Islam *et al.* (2019) found that *I. aquatica* could desalinate saline water at salt concentrations between 1-7 dS/m, improving its quality and making it suitable for irrigation. These novel observations reveal the potential of cultivating *I. aquatica* in saline-prone ecosystems, making it essential in bringing saline soils into cultivation.

2.9.3.2 *Lactuca taraxacifolia* (Wild Lettuce)

Lactuca taraxacifolia, commonly known as Wild Lettuce, is predominantly found in tropical regions and belongs to the Asteraceae family. This upright perennial plant forms a characteristic rosette of leaves at the stem's base. The upper leaves are toothed and exhibit auriculate characteristics, while the lower leaves taper towards their bases (Sakpere and Aremu, 2008). In Ghana, the leaves have a rich history of traditional culinary use and medicinal applications (Adinortey *et al.,* 2012). It is used in various food preparations, including salads, sauces and soups.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Additionally, it serves as fodder for livestock, such as cows, to enhance milk production. When combined with natron (an antibacterial spice), it is fed to sheep and goats to stimulate multiple parturitions (Burkill, 1985).

Several scientific investigations have unveiled the outstanding properties of *Lactuca taraxacifolia* leaves. These leaves have been shown to act as antioxidants (Adinortey *et al.,* 2018) and protect DNA and kidneys from disorders (Adejuwon *et al.,* 2014). Furthermore, they possess antiarthritic and antimicrobial characteristics (Ololade *et al.,* 2017) and are associated with hypolipidaemic effects (Koukoui *et al.,* 2015; Obi *et al.,* 2006).

While specific information regarding the response of *Lactuca taraxacifolia* to salinity stress is limited, studies on related lettuce species, such as *Lactuca sativa* L., are available to provide information that may be similar to that of *L. taraxacifolia*. Salinity stress has been observed to adversely affect the growth, yield, and physiological processes of *L. sativa* L. The osmotic and ionic impacts of salinity influence seed germination, fresh and dry shoot weight, as well as root weight of lettuce (Barassi *et al.,* 2006). Ahmed *et al.* (2019) reported similar findings for *Lactuca sativa*, noting gradual morphological and physiological properties reductions with increasing salt concentrations. Similarly, biochemical properties like proline and protein content significantly increased, while total phenol content gradually decreased as salt stress intensified. Additionally, rising salt stress levels showed a marked reduction in yield.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

2.9.3.3 *Paspalum vaginatum* (Seashore Paspalum)

Paspalum vaginatum O. Swartz, commonly referred to as seashore paspalum, is a warm-season perennial grass classified as a halophyte which is noted to be distributed in tropical and subtropical areas (Riefner and Columbus, 2008). It plays a key role in soil erosion control and environmental restoration (due to its extensive root system), saline and wetland remediation, and feed for livestock (Fontenot, 2007; Barrett-Lennard *et al.,* 2003). It is primarily cultivated on athletic turfs, landscape regions and golf courses (Beard 2002).

The plant is adapted to saline-rich sites due to its efficient ion regulation mechanisms, which show its potential to flourish under adverse environmental stresses (Pessarakli, 2018). Seashore paspalum has the potential to enhance forage productivity even on saline lands significantly. Apart from salinity stress, the plant has endured several stresses, including water stresses, acidic soils, and conditions such as limited shade and radiation exposure (Karimi *et al.,* 2018; Pompeiano *et al.,* 2016).

Comparative assessments of salt tolerance among various grass species consistently reveal seashore paspalum as the most tolerant (Marcum and Murdoch, 1994). Seashore paspalum has been reported to excel in maintaining increased shoot K^+ concentrations while restricting the translocation of Na^+ ions in their roots to the shoots (Wu *et al.,* 2018; Schiavon *et al.,* 2012). This results in a favourable K^+/Na^+ ratio that reduces ion-specific damages from salt-induced stress conditions (Wu *et al.,* 2018; Schiavon *et al.,* 2012). Furthermore, an investigation of the plant found that, in conditions of increased accumulation of Na^+, seashore paspalum

Digitized by Sam Jonah Library

evolves an enhanced Ca^{2+} signalling transduction pathway, which contributes to the preservation of optimal activity levels in critical antioxidant enzymes (Wu *et al.,* 2020). Also, Shahba *et al.* (2012) studied the effects of salinity on seashore paspalum at different mowing heights and found that salinity stress caused increased root mass, leading to reduced plant height. The study concluded that turf quality, canopy photosynthesis, K^+/Na^+ ratio, and total nonstructural carbohydrates were reduced with increasing salt concentrations. In contrast, increased salt concentrations increased shoot proline and total reducing sugars.

2.9.3.4 *Sesuvium portulacastrum* (Shoreline Purslane)

Sesuvium portulacastrum, a member of the Aizoaceae family, is a perennial herb and a facultative halophyte adaptable to saline environments (Lokhande *et al.* 2009; Lonard and Judd 1997). Although it has a taproot system, *S. portulacastrum* also possesses nodal adventitious roots due to its creeping nature. It has greenish-pink or red succulent, sub-terete or trailing smooth herbaceous shoots. These shoots spread out widely and bear succulent simple leaves, which are oppositely arranged, with paracytic stomata (Joshi and Bhosale 1981). It flowers across all seasons. The flowers are vibrant pink to purple, though it occasionally produces white flowers,

Sesuvium portulacastrum flourishes in moisture-laden sandy habitats, including marshes, mangroves, coastal beaches, salt flats and dunes. *Sesuvium* has several response mechanisms when exposed to environmental stressors such as salt, heavy metals and drought. Root and shoot fresh and dry weights, root length, root-to-shoot ratio, leaf area and leaf count significantly reduced when *Sesuvium* were exposed to high amounts of single or combined stress factors (Slama *et al.* 2007a,

Digitized by Sam Jonah Library

2008; Moseki and Buru 2010; Nouairi *et al.* 2006; Messedi *et al.* 2004; Ghnaya *et al.* 2005, 2007a, b; Ramani *et al.* 2004a, b, c; Lokhande *et al.* 2010a, b, 2011a, b). However, the plant is reported to exhibit increased growth when subjected to lower salt concentrations, either alone or when combined with drought and optimal levels of heavy metals. This growth enhancement coincided with balanced mineral ion accumulation, controlled water potential, increased succulence and various physiological and biochemical adjustments, including osmolyte synthesis and antioxidant enzyme activity (Slama *et al.* 2006, 2007a, b, 2008).

Furthermore, upon removing short- or long-term unfavourable conditions, diverse parameters linked to nutrition, hydric status, growth, and development were shown to recover significantly (Slama et al. 2006). It appears that *Sesuvium* conserves its nutrient acquisition and growth potentials during stress conditions and is aided by a reduction in water potential and a rise in water-use efficiency (Slama *et al.* 2006).

As a facultative halophyte classified as a 'salt accumulator', *S. portulacastrum* has been reported to flourish under salinity conditions between 100–400 mM NaCl and nutrient-deprived settings (Lokhande *et al.,* 2013). It accumulates higher concentrations of sodium ions (Na^+) within its vacuoles than its cytoplasm, a distinctive characteristic of succulent halophytes (Yeo and Flowers 1986). *Sesuvium portulacastrum* has been found to adeptly sequester saline ions and heavy metals into vacuoles, thereby keeping an osmotic equilibrium between the cytoplasm and the vacuole (Moseki and Buru 2010; Ramani *et al.,* 2004a, b, c,

Digitized by Sam Jonah Library

2006; Messedi *et al.,* 2004; Ghnaya *et al.* 2005, 2007a, b; Slama *et al.,* 2007a, b, 2008; Lokhande *et al.,* 2010a, b, 2011a, b).

2.9.3.5 *Talinum triangulare* (Waterleaf)

Talinum triangulare (Jacq.), commonly referred to as waterleaf, is a succulent, perennial herb that is extensively cultivated in tropical regions of high humidity as a leafy vegetable (Swarna and Ravindhran, 2013; Swarna *et al.*, 2015). Originating from Central Africa, this plant has become known for its antioxidant properties. It has been associated with the management of various health conditions such as jaundice, stroke, diabetes, cancer, measles, and obesity (Fontem and Schippers, 2004). Its medical relevance extends to cardiovascular health management, attributed to the presence of compounds such as antioxidants and flavonoids (Tiamiyu *et al.,* 2023). *Talinum triangulare* is composed of an array of bioactive constituents, including alkaloids, cardiac glycosides, steroids, phenols, saponins, terpenes, tannins and anthraquinones each possessing reported nutritional and therapeutic significance (Andarwulan *et al.,* 2015; Tiamiyu *et al.,* 2023). Aside from its medicinal qualities, the plant is applied in agricultural and dietary fields. In local contexts, this herb is cultivated in domestic gardens and fields to enhance family nutrition and serve as an income source for farmers (Andarwulan *et al.,* 2015; Fru *et al.,* 2017). The nutritional profile of *T. triangulare* is particularly rich, including essential minerals like magnesium, calcium and potassium, as well as vitamins, pectin and proteins (Andarwulan *et al.,* 2015; Abdulrasheed-Adeleke *et al.,* 2021).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Waterleaf exhibits resilience to diverse soil types, temperature ranges, and moisture levels, growing even in shaded environments. The plant has significant tolerance to saline conditions, with some studies reporting its tolerance to salt concentrations as high as 560 mM NaCl (Bamidele *et al.,* 2007). Under salinity stress, reductions in the leaf, stem, and root fresh biomass by 87% and dry biomass by 82% were observed. In contrast, leaf succulence was unaltered at salinity levels of up to 280 mM NaCl (Bamidele *et al.,* 2007). Additionally, the molar ratio of K/Na declined from 2 to 0.4 with increasing NaCl concentration (Montero *et al.,* 2018). Furthermore, investigations suggest that *Talinum triangulare* can be classified as a halo-tolerant plant due to its reduced K/Na molar ratio when exposed to saline conditions and its relatively minor decrease in growth, mainly evident at very high NaCl concentrations (Chinedum and Kate*,* 2013).

In summary, *Ipomoea aquatica*, *Lactuca taraxacifolia*, *Paspalum vaginatum*, *Sesuvium portulacastrum*, and *Talinum triangulare* exhibit diverse potentials ranging from nutrition and medicinal properties to soil erosion control and phytoremediation. Their resilience in saline environments presents great opportunities for their use in sustainable agriculture and environmental management.

Digitized by Sam Jonah Library

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Identification of Indigenous Halophytes

3.1.1 Study Location

This investigation was conducted on halophytes found along the shore of the Atlantic Ocean close to the South Campus of the University of Cape Coast, Ghana. It took place between 18th and 24th July, 2022. The study site lies between latitude 5° 6` N and longitude 1° 15` W, covering a shoreline distance of approximately 4 km.

3.1.2 Study Procedure

A systematic approach was adopted to identify the halophytes for this study, using the image recognition method developed by Joly et al. (2014). This method leverages the Pl@ntNet Identify website, an advanced web service that integrates images of various plant organs—including fruits, flowers, leaves, bark, and overall habit—to enhance identification accuracy. The Pl@ntNet platform employs sophisticated, machine-learning-based image recognition algorithms, making it highly effective for identifying a wide range of plant species based on their morphological features.

The Pl@ntNet method was selected for its unique ability to handle large-scale image databases and accurately identify plant species across diverse environments and plant morphologies. Its robustness has been demonstrated in multiple studies such as Gaudin (2023), where it achieved reliable identification rates, particularly in ecologically diverse regions similar to our study area. In

Digitized by Sam Jonah Library

addition, Pl@ntNet's interactive platform allows for iterative verification, supporting the accuracy of our identification process (Goëau *et al*., 2014; van Der Velde, 2023). While other plant identification methods exist, such as molecular techniques (e.g., DNA barcoding) and traditional taxonomic approaches, Pl@ntNet was chosen for this study due to its accessibility, cost-effectiveness, and efficiency. Molecular techniques, while accurate, require specialized laboratory equipment and are expensive. Traditional taxonomic keys, on the other hand, can be time-consuming and require expert knowledge for accurate identification, which may limit reproducibility in field-based studies.

Given these considerations, the Pl@ntNet method provided an optimal balance of reliability, accessibility, and efficiency for identifying halophytes in our study, making it a suitable choice to meet the objectives of this research.

Plants within a range of 0-50 meters from the seashore were considered, as this area is known to harbour plant species with high salt tolerance. Clear and detailed images of plants were captured using a high-resolution digital camera (NIKON D5600 Model 20062, SKU 5580110). The captured images were then processed using the Pl@ntNet Identify website (https://identify.plantnet.org/), leveraging its image recognition capabilities. The first four matches were selected for further investigation. Each matched plant was used as search terms in plant repositories including Useful Tropical Plants (https://tropical.theferns.info), World Flora Online (https://worldfloraonline.org), Global Biodiversity Information Facility (https://gbif.org) and JSTOR Global Plants (https://plant.jstor.org) to verify characteristics pertinent to halophytes and examine their individual properties.

Digitized by Sam Jonah Library

Each matched plant was examined based on its growth patterns, particularly focusing on its growth behaviour (whether a shrub, vine, herb, or tree) compared to that observed in the images. In addition, their ecological preferences were assessed to determine whether they could survive and flourish in saline environments such as seashores. Furthermore, their distribution was evaluated to ascertain whether they are found in the tropics and, more specifically, in Ghana. The gathered information was organized in an Excel file, and the best matches for the set characteristics, which included their growth patterns, ecology and distribution, were identified and named.

3.1.3 Categorization and Selection of Identified Plants

For this research, the identified halophytes were subsequently categorized based on their specific attributes, such as their growth patterns, propagation methods, life cycles, and botanical properties. Growth patterns refer to the way plants develop and expand, including upright, trailing, or sprawling habits, which influence their ecological roles. Propagation methods describe how plants reproduce and spread, either sexually through seeds or asexually through structures like stolons, rhizomes, or cuttings. Life cycles pertain to the duration of a plant's life, whether annual, biennial, or perennial, which determines their adaptability to environmental conditions. Botanical properties include distinctive structural features such as leaf thickness, stem type, or root system, which contribute to their classification. Moreover, their practical applications and significance in food, feed, medicine, and ornamental uses were carefully assessed. Criteria for selecting halophytes for subsequent experiments included a combination of desirable

Digitized by Sam Jonah Library

attributes, such as simple propagation methods, high survival rates, short lifecycle, and proven beneficial uses. This systematic approach of identifying and characterising the halophytes ensured a comprehensive selection of the halophytes that possess these desired attributes to aid in the study.

Ipomoea aquatica, *Lactuca taraxacifolia*, *Paspalum vaginatum*, *Sesuvium portulacastrum* were selected from this process for this study due to their multiple beneficial significance, simple propagation methods, high survival rates and short lifecycles. *Talinum triangulare*, a locally beneficial miohalophyte, was used as a control crop.

3.2 Assessing the Desalination Ability of Identified Plants

3.2.1 Study Location

The A. G. Carson Technology Centre of the School of Agriculture at the University of Cape Coast, Ghana, served as the site for the research study. The Centre lies between longitude 1° 15 W and latitude 5° 07 N at an altitude of 1.1 meters above sea level in the Cape Coast municipality in the Coastal Savanna Agro-ecological zone of Ghana (Ampofo, 2006). The area experiences a distinct bi-modal rainfall pattern, characterized by rainfall occurrences during April-July and August-November, contributing to an annual precipitation range of 750-1000 mm (Asare-Bediako *et al.,* 2014). The prevailing weather conditions at the experimental site, described by Adu *et al.* in 2017, have a temperature range of 24°C to 32°C, relative humidity levels ranging from 60% to 80%, solar radiation exposure varying between 3151 kJ $cm^{-2}day^{-1}$ and 3804 kJ $cm^{-2}day^{-1}$, and day lengths spanning from 11.30-12.40 hours.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

3.3 Study of the Level of Salt Tolerance and Remediation Ability of Five (5) of the Identified Halophytes

3.3.1 Study Procedure

Pots, measuring 0.013 m^3, were used in a controlled experiment to assess the salt tolerance and desalination ability of the selected halophytes under different salt stress levels. This enabled the evaluation of their responses to salt stress and identifying the most promising halophytes in terms of tolerance and desalination ability.

3.3.2 Experimental Designs and Treatments

A 5 × 3 × 2 factorial design laid in Completely Randomized Design (CRD) was used in this experiment. The factors were five halophyte species, three (3) levels of salt treatment and two (2) soil types (Table 3.1). Each treatment was replicated four times, resulting in a total of 120 treatment units (5 × 2 × 3 × 4).

Table 3.1: Table of Factors

FACTORS		
Halophyte Species	**Salt Treatment (dS/m)**	**Soil Types**
Ipomoea aquatica	0	Arable soil (UCC)
Lactuca taraxacifolia	25	Sea sand
Paspalum vaginatum	50	
Sesuvium portulacastrum		
Talinum triangulare		

3.3.3 Soil Preparation

The arable soil used in the experiment was obtained from an area adjacent to the Teaching and Research Farm, UCC. It was collected at a 0-15 cm depth, considering the topsoil layer where significant plant-root interactions occur. The soil belonged to the Benya series, classified as a sandy clay loam, specifically

Digitized by Sam Jonah Library

identified as a member of the Edina-Benya association and also classified as a Haplic Acrisol (Asamoah, 1973).

Soil samples were collected from the arable field, processed and analyzed for their physical and chemical properties. The concentrations of exchangeable potassium, magnesium, and calcium, as well as the pH, bulk density, total nitrogen, and accessible phosphorus, were all measured. Similarly, sea sand was gathered from the seashore, meticulously washed to eliminate impurities, and air-dried. Samples were then taken and analyzed for their physical and chemical properties.

3.3.4 Analysis of Initial Soil Physical and Chemical Properties

Soil samples were collected and analyzed to ensure proper characterization and suitability for the study. The methods used in the determination of the soil properties have been described by Kumi *et al.* (2023). The field capacities of the two soil types were determined as described by Cassel and Nielsen, 1986 and Akhter *et al.,* 2004 for arable soil (UCC) and sea sand, respectively. Table 3.2 shows the basic physicochemical characteristics of the soils.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Table 3.2: Physicochemical properties of the soils

Parameter	Unit	Soil type	
		SEA	UCC
Clay	%	-	33
Silt		-	5
Sand		100	63
OC		0.42	1.40
N		0.02	0.06
P	$mg\ kg^{-1}$	0.65	2.25
K		0.97	1.46
Ca		2.17	4.68
Mg		1.04	2.46
BD	$g\ cm^{-3}$	1.80	1.35
pH	-	6.41	5.71

3.3.5 Estimating air-dried soil quantities required to fill pots

A pot was filled with water about 15 cm from the top to determine the air-dried soil required to fill each pot. The volume was then determined by transferring the water into a measuring cylinder, and the volume was recorded. The mass of soil required to attain the same volume of air-dried soil was determined based on the bulk density of the soil type and using the formula below:

$$\text{Bulk Density } (\rho) = \frac{Mass\ of\ soil\ (M)}{Volume\ of\ polybag\ (V)} \qquad \text{Equation (1)}$$

$$\text{Mass of Soil} = \text{Volume of the bag} \times \text{Bulk Density } (\rho) \qquad \text{Equation (2)}$$

Volume of pot (V) = 13, 077 cm^3

For arable soil,

Mass of Soil = 13, 077 cm^3 × 1.3 g/cm^3

= 17, 000 g ≅ 17 kg

Digitized by Sam Jonah Library

For sea sand,

Mass of Soil = 13, 077 $cm^3 \times 1.7$ g/cm^3

= 22, 230 g $\cong$ 22.23 kg

A total of one hundred and twenty (120) pots were filled with the two soil types (Figure 3.1). Sixty (60) each for sea sand or arable soil to a volume of 13 077 cm^3 (22.2 kg of sea sand and 17 kg of arable soil relative to their bulk densities).

Figure 3.1: Set-up of experimental pots

3.3.6 Greenhouse Preparation

The greenhouse used for this experiment was cleared of weeds and fumigated to eliminate pathogens that might have been present in the greenhouse. The pots were then lined in the greenhouse.

3.3.7 Planting Material Preparation and Planting

Due to its low survival rate, the rhizomes of *Lactuca taraxacifolia* and stem cuttings of *Ipomoea aquatica* were initially nursed on beds to encourage shoot sprouting. After two weeks, the resulting shoots were carefully transplanted into the

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

pots. On the other hand, *Paspalum vaginatum*, *Sesuvium portulacastrum*, and *Talinum triangulare* were directly planted into the pots using stem cuttings (Figure 3.2). Cuttings measuring approximately 15 cm long were planted into the pots on the same day. A pot was dedicated to a single halophyte cutting or sprout. Each halophyte species was planted in 24 pots, 12 each in arable soil and sea sand, ensuring adequate representation for the subsequent experimental procedures.

3.3.8 Agronomic practices

3.3.8.1 Irrigation

Before the imposition of the salt treatment, the established plants were irrigated thrice weekly at 100% FC (Appendix 3) to ensure proper plant establishment, growth and development. However, after the imposition of the salt treatment on potted plants, the amount of irrigation water required was determined using moisture probes and was maintained at 60% field capacity for good plant grwth and avoidance of leaching of salt treatments.

Digitized by Sam Jonah Library

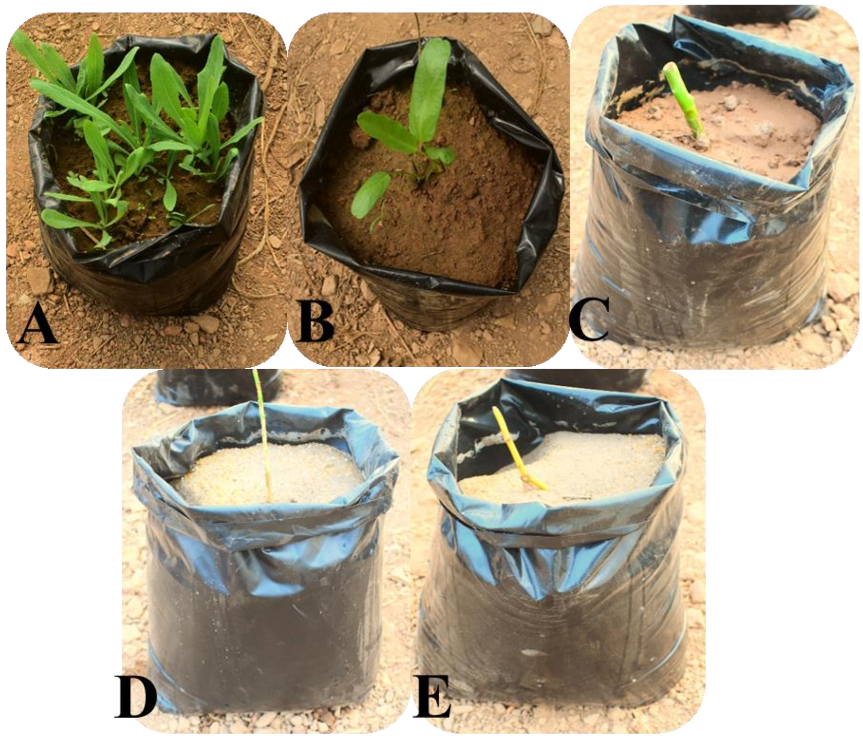


Figure 3.2: Sprouts and cuttings of halophytes after planting. A- *L. taraxacifoliar*, B- *I. aquatica,* C- *T. triangulare*, D- *P. vaginatum* and E- *S. portulacastrum*

Estimating Irrigation Water Required

A gravimetric field capacity method, as illustrated by Topp *et al*., (2008), was used to determine the quantity of water required to irrigate the plants (Appendix 3). Below is a full breakdown of the estimating process.

Percentage moisture at field capacity

The equation below was used for the estimation of field capacity for each soil type:

$$\text{Moisture Percent at Field Capacity} = \frac{Wt\ of\ wet\ soil - Wt\ of\ oven\ dry\ soil}{Wt\ of\ oven\ dried\ soil} \times 100$$

Equation (3)

Digitized by Sam Jonah Library

An average of 4 replicates was used in the estimation of the field capacity

3.3.8.2 Pest control

Pests such as caterpillars, grasshoppers and beetles were controlled by hand-picking.

3.3.8.3 Weed control

Weeds were controlled mostly by hand pulling from pots to reduce competition between the plants and the weeds for space, air, water and nutrients. The greenhouse was manually weeded using a hoe. The weeding was done twice a month.

3.3.9 Preparation and Application of Salt Treatment

Local salt crystals were sourced from the Elmina Market. To achieve experimental salinity levels of 25 and 50 dS/m, salt crystals were added to the irrigation water at approximately 17.5 g/l and 35 g/l respectively, and stirred using a rod, to prepare saline solutions, simulating seawater conditions. The irrigation water without added salt was considered the 0 dS/m (0% added salt) control treatment. A Yinnik Multifunction Meter (BLE-C600) was used to observe the salt concentrations in the saline solutions to ensure that they met the required concentrations of 0, 25 and 50 dS/m concentrations. These salinity levels were selected based on seawater's half and full strength (electrical conductivity). Sea water contains approximately 3.5% $NaCl$ (Doe, 1994).

Drums, measuring 30 L, were used to prepare the salt treatments, ensuring consistent concentrations for application. Each pot, containing 17 kg of arable soil

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

(UCC) and 22 kg of sea sand, received 350 ml of the prepared salt solution once. The experiment was carefully designed to maintain soil moisture at 60% field capacity (FC), and the salt solution volume was adjusted as part of the overall water balance to ensure that the applied salt concentration remained stable.

Salt treatments were imposed one month after planting to ensure that all plant species, regardless of their inherent growth rates, had sufficient time to establish in their new growing environment. Baseline data on plant growth and health parameters (e.g. Plant height, chlorophyll content etc.) were recorded before salt imposition.

3.3.10 Harvesting

Harvesting was conducted ten (10) weeks after the imposition of the salt treatments to standardize the data collection process and facilitate direct comparisons among the selected halophytes. Although the selected plants had different natural maturity times, the focus of this study was not on their maturity or yield at their natural harvest stage but rather on their growth responses and salt tolerance under controlled conditions. The shoots were carefully cut at the soil surface and immediately bagged to prevent moisture loss. They were then sent to the lab for further analysis. The roots were excavated and washed under high-pressure water to remove the soil and debris. They were then sent to the laboratory for further analysis.

Digitized by Sam Jonah Library

3.3.11 Data Collection

3.3.11.1 Morphological and Physiological Parameters

Data on plant height and stem girth was taken. Plant height was measured from the soil's surface to the plant's tip using tape, while the stem circumference was measured using a digital vernier caliper. Also, chlorophyll content, chlorophyll fluorescence (Fv/Fm ratio) and performance index were also observed using a SPAD (Soil Plant Analysis Development) index chlorophyll meter and Hansatech Pocket PEA chlorophyll fluorimeter. Growth data were collected before salt treatment and biweekly afterwards to monitor plant responses and assess the effects of salinity over time. Figure 3.3 shows images of the plants 40 days after salt treatment imposition.

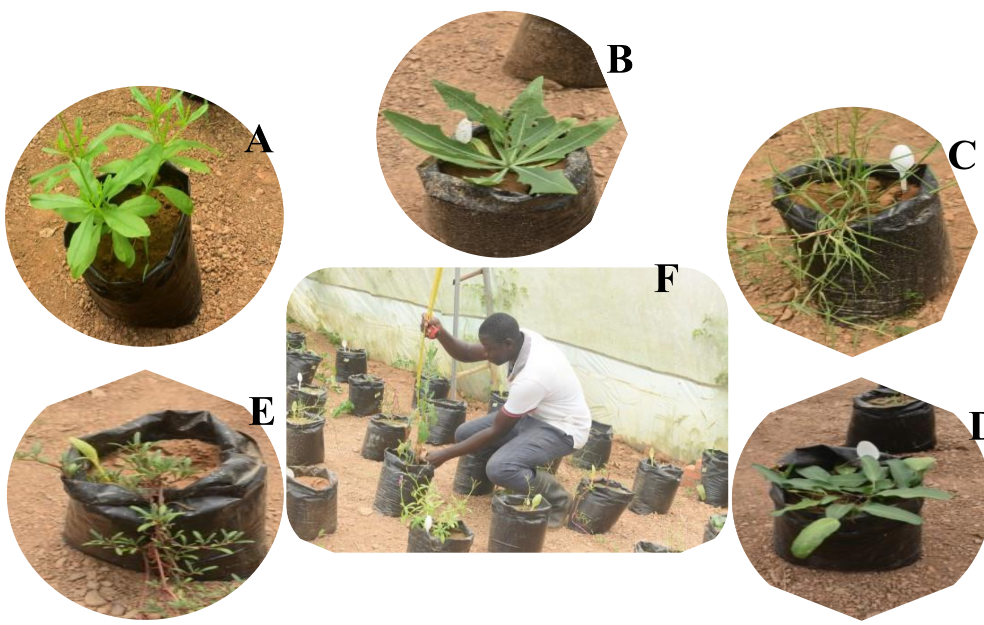


Figure 3.3: Images of plants 40 days after salt treatment imposition. A- *T. triangulare*, B- *L. taraxacifoliar,* C- *P. vaginatum*, D- *I. aquatica,* E- *S. portulacastrum* and F- data collection on plants.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Relative Plant Height Growth Rate

Due to the selected halophytes' different plant types and growth patterns, growth parameters are best represented in relative terms. Plant height Relative Growth Rate (RGR) was calculated for each plant using the following formula:

RGR = $\frac{(\ln W2 - \ln W1)}{t2 - t1}$, where Equation (4)

W2 = the final plant height

W1 = the initial plant height before salt treatment application

T2 = the final week of data taking (i.e., ten weeks after salt imposition)

T1 = the first week of data taking (before salt treatment application)

(Simpson *et al.,* 2018)

3.3.11.2 Measurement of EC, Salt content and pH of the salt-imposed soil sample

Soil samples were taken from the pots for soil analysis before harvest. The soil samples were air-dried, pulverized with a wooden mallet and passed through a 2 mm mesh sieve. The < 2 mm sieved air-dried soil samples were kept for analysis. The EC, TDS and pH were estimated according to Adu *et al.* (2017)) using a Yinnik Multifunction Meter (BLE-C600).

3.3.11.3 Measurement of Shoot and Root Biomass

After harvest, the fresh shoots of halophytes were weighed to obtain their fresh weights, which were recorded. They were then oven-dried to obtain their dry weights. The difference between the shoot fresh and shoot dry weights was

Digitized by Sam Jonah Library

recorded as the tissue moisture content. Samples of both shoots and roots were taken for Na and Cl analysis.

Measurement of Root: Shoot Ratio

To understand the plant's growth strategy and how it invests its resources in different parts of the plant, that is, either to its root or shoot, root to shoot ratio was determined using the following formula:

$$\text{Root: Shoot Ratio} = \frac{Weight\ of\ root\ (g)}{Weight\ of\ shoot\ (g)} \qquad \text{Equation (5)}$$

A root: shoot ratio greater than 1 suggests that the plant invests more biomass in the belowground part (root) than the aboveground part (shoot). This is common in plants adapted to resource-limited environments, where efficient resource uptake and storage are essential for survival.

3.3.11.4 Measurement of sodium and chlorine contents in soil and plant samples

Dry shoot and root biomass were taken to analyze shoot and root Na and Cl content. This was to help identify the plant part of the highest salt accumulation. Na was determined using a flame photometer as described by Thomas and Saunders (1974). Chlorine (Cl) was also determined using the thiocyanate colorimetric method as described by Taras *et al.*, (1975).

3.3.12 Data Analysis

The data was prepared using Microsoft Excel. Statistical analyses were performed using the R software programme version 4.2.1 (R. Core Team, 2022).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Shapiro Wilk's test was conducted to determine normality of the data set. The data was normally distributed. Summary statistics were conducted to give a general idea of the data structure and a fair idea of the descriptive statistics of the data.

Analysis of variances (ANOVA) was performed to determine whether the growth of halophytes was significantly affected by the soil type, salinity treatment, days after salt treatment imposition (DATI) and their interactions. It was also carried out to determine if there were significant differences in salt tolerance, growth parameters, and biomass accumulation among the different halophytes or treatment levels. Again, ANOVA was conducted to determine the differences in the NaCl uptake and accumulation in the shoots and roots of halophytes. This gives an understanding of the level of salt tolerance of the halophytes and the method of salt tolerance or avoidance it exhibits. The factors for the ANOVA were plant species, soil type, salinity level and days after treatment imposition (DATI). The equation below represents the ANOVA model used:

$$Yijk = \mu + \alpha i + \beta j + \gamma k + \delta l + \alpha\beta ij + \alpha\gamma ik + \alpha\delta il + \beta\gamma jk + \beta\delta jl + \gamma\delta kl + \alpha\beta\gamma ijk + \beta\gamma\delta jkl + \alpha\beta\gamma\delta ijkl + \varepsilon ijkl \qquad \text{Equation (6)}$$

Where:

- $Yijkl$ represents the observed response variable for the i^{th} plant type, j^{th} level of salt concentration, the k^{th} soil type and the l^{th} DATI,
- μ is the overall mean of the response variable,
- αi represents the effect of the i^{th} plant type,
- βj represents the effect of the j^{th} level of salt concentration,
- γk represents the effect of the k^{th} soil,
- δl represents the effect of the l^{th} soil,
- $\alpha\beta ij$ represents the interactions between the i^{th} plant type and the j^{th} level of salt concentration,

Digitized by Sam Jonah Library

- $\alpha\gamma ik$ represents the interactions between the i^{th} plant type and the k^{th} soil type,
- $\alpha\delta il$ represents the interactions between the i^{th} plant type and the l^{th} DATI,
- $\beta\gamma jk$ represents the interactions between the j^{th} level of salt concentration and the k^{th} soil type,
- $\beta\delta jl$ represents the interactions between the j^{th} level of salt concentration and the l^{th} DATI,
- $\beta\gamma\delta jkl$ represents the interactions between the j^{th} level of salt concentration, the k^{th} soil type, and the l^{th} DATI,
- $\gamma\delta kl$ represents the interactions between the k^{th} soil type and the l^{th} DATI,
- $\alpha\beta\gamma ijk$ represents the interactions between the i^{th} plant type, the j^{th} level of salt concentration, and the k^{th} soil type,
- $\alpha\beta\gamma\delta ijkl$ represents the interactions between the i^{th} plant type, the j^{th} level of salt concentration, the k^{th} soil type and the l^{th} DATI,
- εijk represents the experimental error.

Where ANOVA detected a significant difference among group means, the Least Significant Difference (LSD) was performed at a 95% confidence level to find the significantly different means. Graphs were created using the ggplot2, dplyr, ggh4x and extrafont packages and libraries in R-studio (R. Core Team, 2022 version 4.2.1).

A correlation analysis was conducted to explore the relationship between salt concentration and growth of the halophytes, as well as the correlation between the various variables.

Digitized by Sam Jonah Library

3.4 Assessing the Ability of Selected Halophyte to Desalinate Saline Water in a Vertical Hydroponic System

3.4.1 Study Procedure

A second controlled experiment was conducted using vertical farming units in a hydroponic system within the same greenhouse. This experiment aimed to further investigate the desalination ability of *Sesuvium portulacastrum*, identified in the pot experiment as the most promising halophyte for salt tolerance and potential water purification. The vertical hydroponic system consisted of a tiered arrangement of planting units, designed to maximize space efficiency and enable continuous water circulation. Vertical farming provides an innovative and resource-efficient approach to cultivation.

3.4.2 Experimental Designs and Treatments

This experiment was a 3 × 4 factorial design laid in RCBD with two blocks, represented by each side of the two-sided vertical farming unit. The two factors were three levels of salt treatment (0, 25 and 50 dS/m) and four planting distances (15, 20, 30 and 40 cm). Only one halophyte was used in this experiment, the most potent from the previous experiment.

3.4.3 Construction of Vertical Farming Structure and Operation of Hydroponic System

The vertical farming unit was constructed using A-shaped wooden frames and PVC pipes (d = 3 inches), while gravel was used as the growth medium. The structure consisted of two A-shaped frameworks positioned 230 cm apart and standing at a height of 170 cm. Parallel racks were affixed to the frameworks (40 cm apart from each other, resulting in 4 racks on each side of the structure), serving

Digitized by Sam Jonah Library

both as support for the structure and as platforms on which the PVC pipes (230 cm long) were positioned (Figure 3.4).

The PVC pipes were partially cut along their length, creating an opening approximately one-fourth the diameter of the pipe to facilitate gravel filling and planting. The pipes were interconnected at their ends to enable water flow from the source at the structure's apex to the pipes at the bottom. This connection was achieved using Equal Tee PVC pipe fittings and 90-degree elbow bend fittings, which joined the pipes at both sides of the structure at the apex (Figure 3.4).

To establish a water circulation system, a submersible pump was connected through a pipe to the fitting at the apex, drawing water from a tank (of volume 200L) and pumping it into the PVC pipes. A bent PVC fitting was used at the base of each end of the structure to redirect the water back into the tank. This design ensured the water would circulate through the pipes, allowing for a continuous water supply cycle and return to the tank. Three vertical farming units were created, each with two sides serving us blocks (Figure 3.4).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Figure 3.4: Vertical farming structure

3.4.5 Water Storage and Operation of Pumps

Water was stored in tanks (200 L) ready for irrigation (Figure 3.5A). There were three tanks, one each of the three vertical farms. Submersible pumps were used to pump the water into the system, one each for the vertical farming units. The RIO SPW1100 (Taam Engineering Company, Iraq) pump brand was used. It had a head pressure of 1.1 KW, power of 1.5 HP, voltage and alternating current of 220V/50Hz, maximum flow rate of 250 L/min, and a size of 1"-1 1/2" (Figure 3.5B). The pumps were regulated to a flow rate of 6 m^3/hour so that the pressure was enough to cause water circulation in the system slowly without causing an overflow or spillage of the water.

3.4.6 Growth Medium and Planting

Gravels were used as the growth medium to securely hold the plants in position and provide temporary water retention. Granite chippings of

Digitized by Sam Jonah Library

approximately 3 cm in diameter were carefully washed with water to clean them of impurities and then filled into the PVC pipes, occupying approximately three-fourths of the pipe's volume. Sprouts of *Sesuvium portulacastrum*, aged two weeks, were transplanted into the pipes of the vertical farm with a cushion wrapped around the sprouts' neck to protect them from bruises. Four planting distances, namely, 15, 20, 30, and 40 cm, were randomly maintained, one for each pipe. This process was replicated on the other side of the unit to form distinct blocks for comparison. The sprouts were trimmed to a height of 10 cm to ensure uniformity.

Figure 3.5: Image of storage tank and hydroponic system – A and submersible pump (Rio SPW 1100) – B.

3.4.7 Fertilizer Application

Since normal tap water was used for the hydropic system, nutrients were supplied to the plants at 2 weeks after planting via foliar application. Polyfeed, commercial foliar fertilizer, was used. It contained 30% Total N, 10% P and K, 500

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

ppm Fe, 250 mm Mn, 75 ppm Zn, 55 ppm Cu and 35 ppm Mo. The fertilizer was applied in the evening to minimize evaporation and enhance nutrient absorption, with three sprays per plant ensuring uniform coverage of the foliage.

3.4.8 Irrigation and Preparation of Saline Solutions

During the initial period after transplanting, irrigation was conducted using normal tap water to acclimate the plants to their new environment. After two weeks, salt treatment was imposed to assess the plant's response to saline conditions in the hydroponic system.

The saline solutions, with salt concentration (%) levels of 0, 1.75, and 3.5%, representing 0, 25 and 50 dS/m, respectively, were prepared like in Objective 2. Each vertical farming unit was assigned to one of the salt treatments, and the corresponding saline solution was stored in a 200 L storage tank at the 150 L mark to save space for the pumps and the delivery pipes. For the 3.5% treatment, 5.25 kg of salt was used, while for the 1.75% treatment, 2.625 kg of salt was used to achieve the desired electrical conductivity level. The irrigation water without added salt served as the 0% control treatment.

3.4.9 Data Collection

3.4.9.1 Weather Data

Temperature and relative humidity readings outside and inside the greenhouse were monitored and recorded daily with a Denver weather data logger WS-520 (Denver A/S, Denmark).

Digitized by Sam Jonah Library

3.4.9.2 Morphological and Physiological Parameters

Data on plant height and stem girth was taken. Plant height was measured from the gravel's surface to the plant's tip using tape, while stem circumference was measured with a digital vernier caliper. Also, chlorophyll content and leaf temperature were observed using a SPAD metre and thermometer gun, and measurements were taken for all the plants biweekly before the imposition of salt treatment.

3.4.9.3 Measurement of Shoot and Root Biomass and ratio

After harvest, the shoots and roots were weighed to obtain their fresh weights, which were recorded. They were then oven-dried to obtain their dry biomass weights. Samples of both shoots and roots were taken for Na and Cl analysis. The root-to-shoot ratio was determined as explained earlier.

3.4.9.4 Measurement of sodium and chlorine in soil and plant

Dry shoot and root biomass were taken to analyze shoot and root Na and Cl content. Na was determined using a flame photometer, while Cl was also determined using the thiocyanate colorimetric method as described by Taras *et al.*, (1975).

3.4.9.5 Measurement of EC, Salt content and pH of irrigation solution

To closely monitor the progress of the plant's ability in reducing the salt concentration of the irrigation solution, the electrical conductivity (EC), salt content, and pH of the solution were measured frequently using a Yinnik Multifunction Meter (BLE-C600) before starting the hydroponic system. This process helped prepare additional salt solutions to replenish the tanks when water

Digitized by Sam Jonah Library

loss occurred due to evapotranspiration. Concentrated solutions were not added to the tanks once water levels were significantly reduced to observe the desalination progress accurately. Instead, the instant EC of the water was measured, and in situations where it was lower than the initial EC (0, 25 and 50 dS/m), a solution with a similar EC was prepared and added to the tanks. Otherwise, a solution with a similar EC as the initial solution was prepared and added. The daily water loss due to evapotranspiration was measured by monitoring the tank's water volume changes over time.

3.4.10 Data Analysis

The data was prepared using Microsoft Excel. Statistical analyses were performed using the R software programme version 4.2.1 (R. Core Team, 2022). Summary statistics were conducted to give a general idea of the data structure and a fair idea of the descriptive statistics of the data.

Analysis of variances (ANOVA) was performed to determine if the growth of *S. portulacastrum* was significantly affected by the planting distances and salt concentrations of the hydroponic water. It was also carried out to determine if there were significant differences in growth parameters, water use efficiency, and biomass accumulation among the different treatment factors and levels. The factors for the ANOVA were salinity level and planting distance. The equation below represents the ANOVA model used;

$$Yij = \mu + \alpha i + \beta j + \alpha\beta ij + \varepsilon ij \qquad \text{Equation (7)}$$

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Where:

- *Yij* represents the observed response variable for the i^{th} level of salt concentration and the j^{th} level of planting distance,
- μ is the overall mean of the response variable,
- αi represents the effect of the i^{th} level of salt concentration,
- βj represents the effect of the j^{th} level of planting distance,
- $\alpha\beta ij$ represents the interactions between the i^{th} level of salt concentration and the j^{th} level of planting distance and
- εij represents the experimental error.

Where ANOVA detected a significant difference among group means, the Least Significant Difference (LSD) was performed at a 95% confidence level to find the significantly different means. Graphs were created using the ggplot2, dplyr, ggh4x and extrafont packages and libraries in R (R. Core Team, 2022 version 4.2.1) and Microsoft Excel (2022 version).

A correlation analysis was conducted to explore the relationship between salt concentration and growth of the halophyte, as well as the correlation between water use efficiency and biomass accumulation.

Digitized by Sam Jonah Library

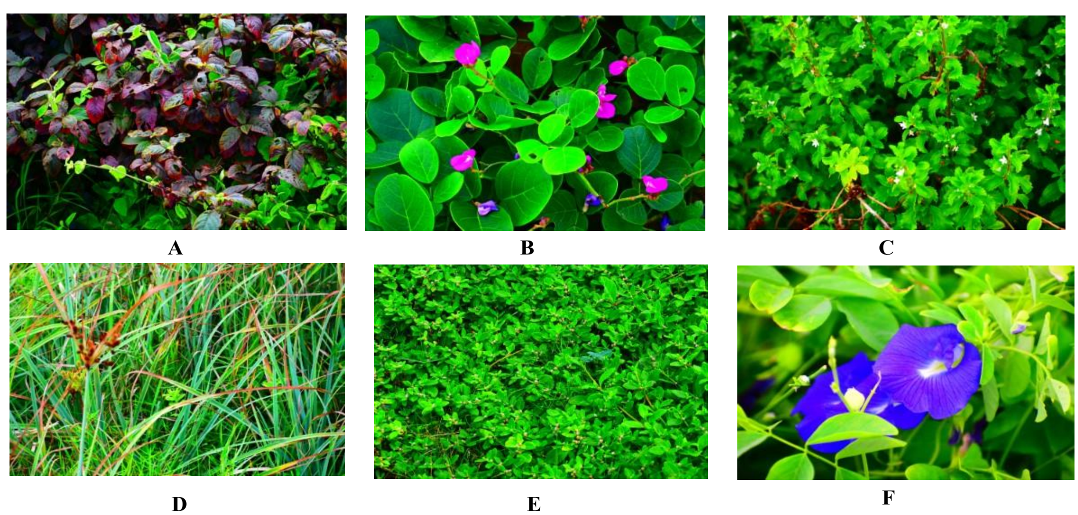
CHAPTER FOUR

4.0 RESULTS

4.1 Diversity of Halophytes along the shorelines of Cape Coast

In this study, 20 halophytes were identified from the identification process carried out (Figure 4.1). *Talinum triangulare*, a common vegetable in Ghanaian communities, was added to the identified halophytes. This addition is based on its classification as a miohalophyte by Bamidele *et al.* (2007). Including *T. triangulare* among the identified halophytes enhances the study's relevance and relatability to the local environment.

Nearly half (48%) of the identified halophytes were herbaceous plants. Shrubs and succulent plants each constituted 14% of the identified plants (Table 4.1). Also, two-thirds of the halophytes were perennials, while the remaining third were annuals (Table 4.1).



Digitized by Sam Jonah Library

Figure 4.1: Halophytes identified in this study. **A**. *Amaranthus spp.* **B**. *Canavalia rosea* **C**. *Capraria biflora* **D**. *Cyperus ligularis* **E**. *Euphorbia albomarginata* **F**. *Clitoria ternatea* **G**. *Furcarear cabuya* **H**. *Indogofera spicata* **I**. *Sansevieria masoniana* **J**. *Ipomoea aquatica* **K**. *Ipomoea asarifolia* **L**. *Kalanchoe daigremontiana* **M**. *Lactuca taraxacifoliar* **N**. *Opuntia spp.* **O**. *Paspalum vaginatum* **P**. *Pedalium murex* **Q**. *Physalis spp* **R**. *Pupalia lappacea* **S**. *Sesuvium portulacastrum* **T**. *Cocos nusifera* **U**. *Talinum triangulare*

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Regarding growth habits, most (71%) of the halophytes are upright plants, 14% are vines, and the remaining are palm or prostrate. All the identified halophytes had potential uses ranging from food to medicine and environmental sustenance (Table 4.1).

4.2 Assessing the Desalination Ability of Identified Plants in Soil Media

4.2.1 Effects of Salt Concentration and Soil Type on the Plant Growth

4.2.1.1 Relative Height Growth Rate (RHGR)

The plant species and two soil types had a highly significant ($p < 0.001$) impact on the relative height growth rate of the halophytes. Similarly, salt concentrations significantly ($p < 0.01$) influenced RHGR. The three-way interaction of plant, soil type and salt concentration also had a highly significant ($p < 0.001$) effect on the relative height growth rate (Table 4.2).

Paspalum vaginatum (averaging 0.12 cm/week) and *S. portulacastrum* (averaging 0.11 cm/week) had the highest RHGR at increased salt concentrations among the halophytes, followed by *L. taraxacifoliar* (0.09 cm/week) and *I. aquatica* (0.08 cm/week), with *T. triangulare* (0.04 cm/week) having the least (Figure 4.2). UCC soil generally impacted RHGR (ranging from 0.03 to 0.13 cm/week) on plants than sea soil (ranging from 0.02 to 0.13 cm/week) (Figure 4.2). Also, the RHGR for the halophytes decreased with increasing salt concentrations except for *P. vaginatum* and *S. portulacastrum,* which exhibited increased RHGR with increasing salt concentrations.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

4.2.1.2 Biomass Accumulation

Both shoot and root dry weights were significantly ($p < 0.001$) affected by both soil types and salt concentrations as well as their interactive effects (Table 4.3). Generally, UCC soil (197 g, 41.68, 19.35, 32.44) significantly increased both shoot dry weight (SDW) and root dry weight (RDW) by 373% and 68% respectively, compared to sea sand in all plant species (Table 4.3). The increase in salt concentration reduced SDW and RDW in *I. aquatica*, *L. taraxacifoliar* and *T. triangulare*. However, the SDW of *S. portulacastrum* increased with increasing salt concentration. In contrast, salt concentration had no significant effect on the SDW of *P. vaginatum* but had significant effects on the RDW, with increasing salt concentration leading to increased RDW. Also, increased salt concentration significantly reduced the RDW of *S. portulacastrum*. *Paspalum vaginatum* had the highest biomass accumulation (SDW = 29.99 g, RDW = 4.03 g), followed by *S. portulacastrum,* which also had a significantly higher biomass accumulation (SDW = 23.2 g, RDW = 1.4 g) as compared to the other three halophytes (Table 4.4). *I. aquatica* also had an appreciable biomass accumulation (SDW = 10.61 g, RDW = 1.8 g) as compared to *L. taraxacifoliar* and *T. triangulare* which had very low SDW but relatively higher RDW (SDW for *L. taraxacifoliar* = 5.59 g, RDW for *L. taraxacifoliar* = 3.5 g; SDW for *T. triangulare* = 5.27 g, RDW for *T. triangulare* = 3.1 g) (Table 4.3).

Digitized by Sam Jonah Library

Table 4.1: Characteristics of identified halophytes

Botanical Name	Plant Type	Family	Growth Habit	Lifecycle	Potential Uses or Importance	References
Amaranth spp.	Herbaceous plant	Amaranthaceae	Upright, bushy	Annual	Medicinal and ornamental plant	Aderibigbe *et al.*, (2022) and Baraniak & Kania-Dobrowolska (2022)
Canavalia rosea	Herbaceous plant	Fabaceae	Vine	Perennial	Erosion control, nitrogen fixation, ornamental plant	Lin *et al.* (2021) and Huang *et al.* (2019)
Capraria biflora	Shrub	Scrophulariaceae	Upright	Perennial	Medicinal plants used in traditional medicine	Vasconcellos *et al.*, (2005) and Duke (2008)
Clitoria ternatea	Climbing vine	Fabaceae	Vine	Perennial	Edible flowers, herbal tea, natural food colouring, forage	Suarna and Wijaya (2021) and Morris (2023)
Cyperus ligularis	Herbaceous plant	Cyperaceae	Upright	Perennial	Wetland habitat (Phytodepuration), erosion control, ornamental plant	Casierra-Martínez *et al.*, (2017) and Fontalvo *et al.*, (2011)
Euphorbia albomarginata	Shrub	Euphorbiaceae	Upright	Perennial	Medicinal plants used in traditional medicine for various ailments	Rojas *et al.* (2010)
Furcarea cabuya	Herbaceous plant	Asparagaceae	Upright	Annual	Traditional medicinal plants, used for various ailments in herbal medicine and leaves are used for making handicrafts.	PFAF (2024)

Digitized by Sam Jonah Library

Indigofera spicata	Shrub	Fabaceae	Upright	Perennial	Soil improvement, forage for livestock, traditional dye plant and medicine	Mouafon *et al.*, (2021) and Heuzé *et al.*, (2016)
Ipomoea aquatica	Semi-aquatic vine	Convolvulaceae	Vine	Perennial	Edible leaves, aquatic plants used in culinary dishes and phytoremediation	Malakar *et al.*, (2015) and Rai and Sinha (2001)
Ipomoea asarifolia	Herbaceous plant	Convolvulaceae	Upright	Annual	Ground cover, medicine	Albuquerque et al., (2007), Burkill, (2004)
Kalanchoe daigremontiana	Succulent plant	Crassulaceae	Upright	Perennial	Ornamental plants, used in traditional medicine for various purposes	Navarrete *et al.*, (2021)
Lactuca taraxacifolia	Herbaceous plant	Asteraceae	Upright	Annual	Edible leaves, salad green	Adebisi (2004) and Adinortey *et al.*, (2012)
Opuntia spp.	Cactus	Cactaceae	Upright	Perennial	Edible fruits, forage for livestock, soil erosion control	Díaz *et al.*, (2017) and Ciriminna *et al.*, (2019)
Paspalum vaginatum	Grass	Poaceae	Upright	Perennial	Turfgrass, erosion control, forage for livestock	Fabbri *et al.*, (2016) and Parker (2022).
Pedalium murex	Herbaceous plant	Pedaliaceae	Upright	Annual	Medicinal plants used in traditional medicine for various ailments and for rhizoremediation	Shekhar *et al.*, (2021), Sahayaraj and Sathyamoorthi (2010) and Tripathi *et al.*, (2021)
Physalis spp.	Herbaceous plant	Solanaceae	Upright	Annual	Edible fruits and medicinal plants used in traditional medicine	Daunay *et al.*, (2007) and Popova *et al.*, (2020)

Digitized by Sam Jonah Library

Pupalia lappacea	Herbaceous plant	Asteraceae	Upright	Annual	Erosion control, a medicinal plant used in traditional medicine	Naidu and Rajesh (2014) and Barkhadle *et al.* (1994)
Sansevieria masoniana	Succulent plant	Asparagaceae	Upright	Perennial	Ornamental plant, air purifier	Chahinian, (2000) and Boraphech *et al.*, 2016
Sesuvium portulacastrum	Succulent plant	Aizoaceae	Prostrate	Perennial	Soil stabilization, edible leaves, phytoremediation	Lokhande *et al.*, (2013) and He *et al.*, (2022)
Cocos nucifera	Palm tree	Arecaceae	Palm	Perennial	Edible coconut fruit, oil, fibre, water, various industrial and culinary uses	Pham, (2016) and Siriphanich *et al.* (2011)
Talinum triangulare	Herbaceous plant	Talinaceae	Upright	Perennial	Edible leaves, a medicinal plant used in traditional medicine	Pavithra *et al.*, (2017) and Aja *et al.*, (2010)

Digitized by Sam Jonah Library

Table 4.2: F and P- values of RHGR (relative height growth rate), SDW (shoot dry weight), RDW (root dry weight) and R:S ratio (root to shoot ratio) as affected by salt concentration, soil type and plant species.

Source of Variance	Df	RHGR		SDW		RDW		R:S Ratio	
		F-value	P- value	F-value	P- value	F-value	P- value	F-value	P- value
Plant	4	3262.85	1.83×10^{-96}	1637.39	4.00×10^{-83}	699.61	7.25×10^{-67}	512.84	5.06×10^{-61}
Soil	1	44.18	2.25×10^{-9}	5616.37	6.7×10^{-83}	1226.10	3.25×10^{-54}	1051.13	2.00×10^{-51}
Salt	2	1026.19	1.12×10^{-62}	18.12	2.44×10^{-07}	93.53	1.06×10^{-22}	12.06	2.30×10^{-05}
Plant * Soil	4	10.01	9.52×10^{-07}	725.31	1.50×10^{-67}	222.143	9.68×10^{-46}	111.60	4.99×10^{-34}
Plant * Salt	8	342.81	6.17×10^{-64}	38.42	7.75×10^{-26}	153.58	4.83×10^{-49}	2.44	0.019
Soil * Salt	2	6.39	0.0025	3.29	0.042	12.85	1.24×10^{-05}	1.5	0.22
Plant * Soil * Salt	8	5.10	2.98×10^{-05}	11.11	8.58×10^{-11}	10.22	4.71×10^{-10}	2	0.056
Rep.	3	1.08	0.36	0.47	0.70	1.32	0.27	1.21	0.31
Residuals	90	NA	NA	NA	NA	NA	NA	NA	NA

Digitized by Sam Jonah Library

Also, root to shoot ratio was significantly affected by the soil and salt treatments ($p < 0.001$). However, the interactions of these three factors had no significant effect on the R:S ratio ($p = 0.06$). UCC soil (0.06 to 0.63 g) resulted in a significantly lower R:S ratio than sea sand (0.11 to 1.66 g), which recorded values more than two-fold that of the UCC soil. The effect of salt concentration varied, but generally, higher salt concentrations led to a lower R:S ratio in all plant types except for *P. vaginatum* (from 0.42 at 0 dS/m to 0.46 at 50 dS/m), which recorded a higher R:S ratio at increased salt concentrations. *Lactuca taraxacifoliar* and *T. triangulare* had the highest R:S ratio (1.66 g and 1.53 g respectively) while *S. portulacastrum* had the lowest (0.06 g) (Table 4.3).

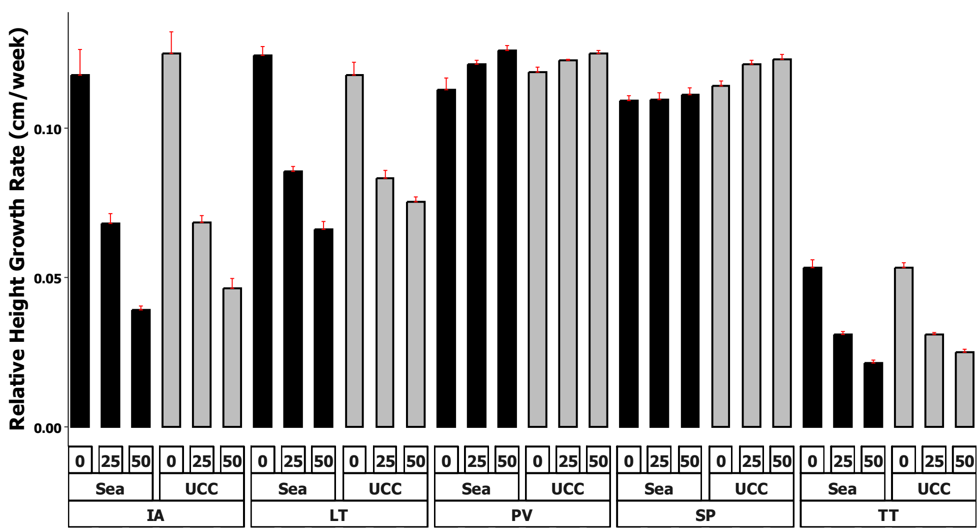


Figure 4.2: Effects of Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Relative Height Growth rate of the different Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

4.2.1.3 Tissue Water Content (TWC)

Tissue water content of the various plant types was significantly affected by both salt concentrations ($p < 0.001$) and soil types ($p < 0.001$). The plant types also exhibited significantly high ($p < 0.001$) differences in the % of moisture accumulated in their tissues. The interactive effects of the three main factors, plant type, salt concentrations and soil type, were also highly significant ($p < 0.001$). The tissue water content ranged from as low as 61.28% for *P. vaginatum* at 50 dS/m in UCC soil to as high as 92.81% for *S. portulacastrum* at 25 dS/m. *Paspalum vaginatum* generally had the lowest TWC (61.28% to 69.15%) while *S. portulacastrum* had the highest (76.66% to 92.81%). *Talinum triangulare*, *L. taraxacifoliar* and *I. aquatica* also had fairly high TWC values ranging from 69.45% to 92.62% (Figure 4.3). The TWC generally decreased with increasing salt concentrations.

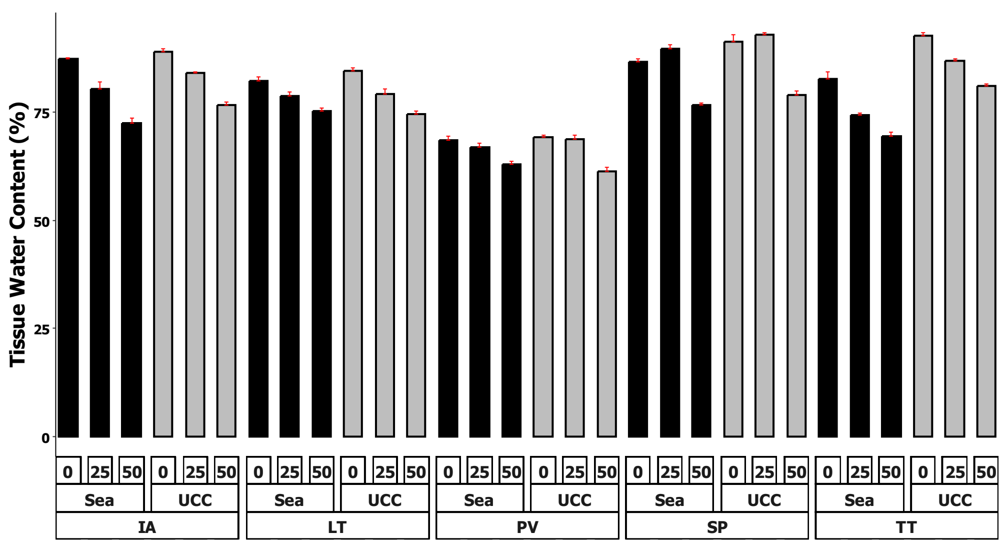


Figure 4.3: Effects of Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Tissue Water Content of the different Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

4.2.2 Effects of Salt Concentration and Soil Type on the Plant Photosynthetic Parameters Over Time

4.2.2.1 Leaf Temperature

Leaf temperature was significantly affected by the plant type ($p < 0.001$), salt concentrations ($p < 0.001$), soil types ($p < 0.001$) and days after salt treatment imposition (DATI) ($p < 0.001$) (Table. 4.4). The different interactions among these factors also had significant influence on the leaf temperature with the interactions among plant, soil type, salt concentration and days of treatment imposition (DATI) being very significant ($p < 0.001$).

Across the various treatment factors, leaf temperature ranged from 28.25 °C to 41.6 °C, with a calculated average least significant difference (LSD) of 1.29 at a 95% confidence level (Table 4.4). Generally, leaf temperature was higher at 80 DATI (average 34 °C) than at 40 DATI (average 30 °C). The salt treatments resulted in higher leaf temperatures across all plant and soil types, with 50 dS/m recording the highest leaf temperatures within the range of 30.98 to 39.53 °C. On the other hand, at 0 dS/m, the plants had very similar leaf temperatures ranging from 28.25 to 34.93 °C (Table 4.4).

4.2.2.2 Fv/Fm Ratio

There were highly significant differences ($p < 0.001$) in the fv/fm ratio among the plant species, salt concentrations and soil types. The fv/fm ratio ranged between 0.61 and 0.84, with UCC soil (between 0.69 and 0.84) having relatively higher ratios than sea sand (between 0.61 and 0.84). Generally, the fv/fm ratio decreased with increasing salt levels 40 and 80 days after treatment imposition (DATI).

Digitized by Sam Jonah Library

Table 4.3: Effects of salt concentrations and soil type on SDW (shoot dry weight, g), RDW (root dry weight, g) and R:S Ratio (root to shoot ratio) of selected halophytes.

PLANT	SALT	SDW (G)		RDW (G)		R:S RATIO	
		Sea	UCC	Sea	UCC	Sea	UCC
IA	0	1.70 ± 0.15	10.61 ± 0.43	1.17 ± 0.05	1.80 ± 0.05	0.69 ± 0.06	0.17 ± 0.00
	25	1.19 ± 0.04	8.95 ± 0.54	0.70 ± 0.04	1.28 ± 0.07	0.59 ± 0.03	0.14 ± 0.00
	50	0.97 ± 0.09	7.96 ± 0.29	0.43 ± 0.03	1.05 ± 0.06	0.45 ± 0.05	0.14 ± 0.01
$LSD_{0.05}$		0.18	0.56	0.08	0.12	0.1	0.01
LT	0	0.59 ± 0.03	5.59 ± 0.21	0.97 ± 0.08	3.50 ± 0.16	1.66 ± 0.11	0.63 ± 0.04
	25	0.38 ± 0.03	4.65 ± 0.30	0.57 ± 0.03	2.90 ± 0.15	1.50 ± 0.14	0.63 ± 0.05
	50	0.28 ± 0.02	3.81 ± 0.20	0.39 ± 0.02	2.00 ± 0.11	1.39 ± 0.10	0.53 ± 0.05
$LSD_{0.05}$		0.04	0.04	0.1	0.19	0.21	0.08
PV	0	3.47 ± 0.27	25.45 ± 2.42	1.44 ± 0.20	2.38 ± 0.15	0.42 ± 0.07	0.09 ± 0.01
	25	5.32 ± 0.25	28.93 ± 1.72	2.61 ± 0.20	3.50 ± 0.17	0.49 ± 0.04	0.12 ± 0.01
	50	5.69 ± 0.12	29.99 ± 2.15	2.62 ± 0.14	4.03 ± 0.23	0.46 ± 0.01	0.13 ± 0.01
$LSD_{0.05}$		0.46	3.92	0.33	0.35	0.08	0.02
SP	0	4.46 ± 0.32	14.62 ± 0.25	0.61 ± 0.04	1.40 ± 0.10	0.14 ± 0.01	0.10 ± 0.01
	25	6.57 ± 0.28	20.23 ± 0.37	0.79 ± 0.03	1.27 ± 0.14	0.12 ± 0.00	0.06 ± 0.01
	50	6.58 ± 0.31	23.20 ± 1.41	0.68 ± 0.03	1.22 ± 0.04	0.11 ± 0.01	0.06 ± 0.01
$LSD_{0.05}$		0.39	1.61	0.06	0.19	0.02	0.01
TT	0	1.93 ± 0.19	5.27 ± 0.30	2.73 ± 0.15	3.10 ± 0.20	1.43 ± 0.18	0.59 ± 0.06
	25	1.47 ± 0.23	4.46 ± 0.37	2.21 ± 0.21	1.85 ± 0.22	1.53 ± 0.33	0.42 ± 0.07
	50	1.08 ± 0.06	3.28 ± 0.23	1.43 ± 0.27	1.16 ± 0.08	1.32 ± 0.20	0.35 ± 0.01
$LSD_{0.05}$		0.30	0.56	0.38	0.27	0.45	0.09

The plant types were IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*. The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD)

Digitized by Sam Jonah Library

Table 4.4: Effects of salt concentrations and soil type on Leaf temperature (°C) and Fv/fm ratios of selected halophytes.

PLANT	SALT	Leaf Temperature (°C)				Fv/fm Ratio			
		Sea		UCC		Sea		UCC	
		40	80	40	80	40	80	40	80
IA	0	31.05 ± 1.18	31.05 ± 1.18	31.65 ± 0.87	32.40 ± 0.98	0.81 ± 0.02	0.83 ± 0.02	0.83 ± 0.01	0.84 ± 0.01
	25	31.93 ± 0.59	35.40 ± 0.45	32.55 ± 1.07	35.10 ± 1.10	0.71 ± 0.01	0.69 ± 0.01	0.81 ± 0.01	0.79 ± 0.01
	50	32.53 ± 0.88	37.53 ± 0.88	33.55 ± 1.44	38.98 ± 1.19	0.72 ± 0.01	0.69 ± 0.01	0.77 ± 0.01	0.72 ± 0.01
$LSD_{0.05}$		1.48	1.5	1.43	2.28	0.02	0.02	0.01	0.01
LT	0	30.23 ± 0.33	30.23 ± 0.33	31.40 ± 1.63	31.65 ± 0.40	0.82 ± 0.02	0.84 ± 0.01	0.84 ± 0.01	0.84 ± 0.02
	25	32.98 ± 1.50	35.18 ± 0.97	30.58 ± 1.80	30.58 ± 1.80	0.72 ± 0.02	0.69 ± 0.01	0.78 ± 0.01	0.76 ± 0.01
	50	32.28 ± 0.57	34.78 ± 1.05	30.98 ± 0.39	35.10 ± 0.71	0.72 ± 0.01	0.71 ± 0.01	0.81 ± 0.01	0.76 ± 0.03
$LSD_{0.05}$		1.54	1.62	2.45	1.87	0.02	0.02	0.02	0.04
PV	0	34.93 ± 0.36	31.98 ± 1.20	31.85 ± 0.52	31.13 ± 0.48	0.77 ± 0.01	0.79 ± 0.01	0.83 ± 0.01	0.83 ± 0.01
	25	38.90 ± 0.35	41.60 ± 0.82	37.20 ± 1.00	37.20 ± 0.27	0.76 ± 0.01	0.74 ± 0.01	0.76 ± 0.03	0.77 ± 0.01
	50	38.65 ± 0.44	39.53 ± 0.41	31.48 ± 0.82	31.48 ± 0.82	0.77 ± 0.02	0.74 ± 0.02	0.79 ± 0.02	0.76 ± 0.02
$LSD_{0.05}$		0.69	1.62	1.31	1.04	0.02	0.02	0.03	0.03
SP	0	30.93 ± 0.71	30.50 ± 0.81	30.68 ± 0.59	28.95 ± 1.10	0.82 ± 0.01	0.83 ± 0.01	0.82 ± 0.01	0.80 ± 0.01
	25	32.35 ± 0.81	30.68 ± 0.50	32.83 ± 2.60	32.83 ± 2.60	0.80 ± 0.01	0.81 ± 0.01	0.82 ± 0.01	0.80 ± 0.01
	50	36.88 ± 0.45	37.05 ± 0.21	35.20 ± 0.32	36.50 ± 0.41	0.80 ± 0.03	0.80 ± 0.01	0.82 ± 0.01	0.79 ± 0.01
$LSD_{0.05}$		0.97	0.61	2.41	2.45	0.02	0.01	0.02	0.02
TT	0	31.15 ± 0.71	30.38 ± 0.48	29.10 ± 0.27	28.25 ± 0.50	0.80 ± 0.01	0.81 ± 0.01	0.80 ± 0.01	0.84 ± 0.01
	25	36.25 ± 0.41	36.98 ± 0.17	32.60 ± 0.16	34.55 ± 0.41	0.78 ± 0.05	0.81 ± 0.02	0.72 ± 0.01	0.69 ± 0.01
	50	36.43 ± 0.35	37.60 ± 0.43	32.83 ± 0.24	34.38 ± 0.10	0.66 ± 0.02	0.61 ± 0.01	0.72 ± 0.01	0.69 ± 0.01
$LSD_{0.05}$		0.71	0.56	0.41	0.5	0.05	0.02	0.01	0.01

The plant types were IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*. The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

The fv/fm ratio ranged from 0.77 to 0.84 at 0 dS/m while it ranged between 0.61 and 0.82 at 25 and 50 dS/m. At 40 DATI, fv/fm ratios averaged 0.78, while it averaged 0.77 at 80 DATI (Table 4.4).

4.2.2.3 Chlorophyll Content

Plant type ($p < 0.001$), salt concentrations ($p < 0.001$), soil types ($p < 0.001$) and days after salt treatment imposition (DATI) ($p < 0.001$) all had significant effects on the chlorophyll content. All the interactions among the factors significantly ($p < 0.001$) affected the chlorophyll content. The chlorophyll content values ranged from 101.78 SPAD to 60.1 SPAD. *Sesuvium portulacastrum* (with a mean of 86.2 SPAD) had relatively higher chlorophyll content than all the other plant types while *L. taraxacifoliar* (34.3 SPAD) and *T. triangulare* (33.38 SPAD) had the lowest readings.

Generally, chlorophyll content decreased with increasing salt concentrations across the plant types except for *P. vaginatum* in UCC soil and *S. portulacastrum* in sea sand, where slight variations were observed. Salt concentrations at 50 dS/m recorded the lowest chlorophyll content between 17.55 and 80.3 SPAD. Also, chlorophyll content was generally higher in UCC soil (averaging 59.44 SPAD) than in sea sand (43.12 SPAD). Averagely, chlorophyll content was very similar at 40 and 80 DATI, that is, 51.45 SPAD and 51.11 SPAD, respectively (Table. 4.5).

Digitized by Sam Jonah Library

Table 4.5: Effects of salt concentrations and soil type on Chlorophyll Content (SPAD readings) of selected halophytes.

PLANT	SALT	Sea sand 40 days	Sea sand 80 days	UCC soil 40 days	UCC soil 80 days
IA	0	53.48 ± 2.02	60.63 ± 2.20	71.60 ± 1.89	78.45 ± 0.73
	25	37.55 ± 3.27	33.23 ± 1.60	63.50 ± 0.91	57.10 ± 1.11
	50	39.03 ± 2.19	33.15 ± 2.12	53.48 ± 2.75	46.38 ± 2.38
$LSD_{0.05}$		5.02	3.32	3.27	2.86
LT	0	33.45 ± 1.32	40.00 ± 4.03	56.65 ± 1.17	64.35 ± 0.83
	25	21.48 ± 1.63	18.48 ± 0.89	44.85 ± 2.38	34.13 ± 2.46
	50	18.80 ± 0.88	15.30 ± 1.02	38.70 ± 1.85	25.35 ± 1.45
$LSD_{0.05}$		1.76	4.31	2.67	2.44
PV	0	41.93 ± 0.52	45.38 ± 0.56	56.60 ± 2.23	60.00 ± 1.33
	25	37.58 ± 1.49	43.20 ± 0.77	58.25 ± 1.51	63.30 ± 0.75
	50	36.68 ± 1.28	40.08 ± 1.17	57.83 ± 1.15	61.73 ± 1.12
$LSD_{0.05}$		1.61	1.27	3.08	1.86
SP	0	79.08 ± 1.48	82.05 ± 1.14	101.78 ± 3.48	98.70 ± 2.84
	25	93.40 ± 2.17	99.15 ± 1.32	95.28 ± 1.40	98.10 ± 1.22
	50	68.70 ± 1.59	60.10 ± 1.57	80.30 ± 3.02	77.80 ± 4.33
$LSD_{0.05}$		3.57	2.69	5.1	4.2
TT	0	34.63 ± 0.49	39.43 ± 0.79	53.05 ± 0.54	60.93 ± 1.35
	25	26.35 ± 0.64	21.95 ± 0.59	33.80 ± 9.88	33.80 ± 9.88
	50	21.80 ± 1.06	17.55 ± 0.87	33.90 ± 1.58	23.40 ± 0.65
$LSD_{0.05}$		1.47	1.46	10.43	10.66

The plant types were IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*. The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

4.2.2.4 Performance Index (PI)

The performance index of the plants varied greatly among the salt treatments and soil types ($p < 0.001$). The interactions between the three factors were also significant ($p < 0.001$). The PI ranged from 1.2 to 11.89, with a mean of 5.84. Generally, the performance index tended to reduce with increasing salt concentrations, recording values between 4.24 and 11.88 at 0 dS/m and 1.12 and 11.88 at 25 and 50 dS/m. *Sesusium portulacastrum* had the highest mean PI of

Digitized by Sam Jonah Library

10.25, which is almost twice that of the second highest, *P. vaginatum* (5.83) followed by *I. aquatica* (5.17), *T. triangulare* (4.07) and with *L. taraxacifoliar* having the lowest readings of 3.89. UCC soil recorded higher PI values ranging from 2.47 to 11.89 for the soil types, while sea sand had values between 1.2 and 11.83 (Figure 4.4).

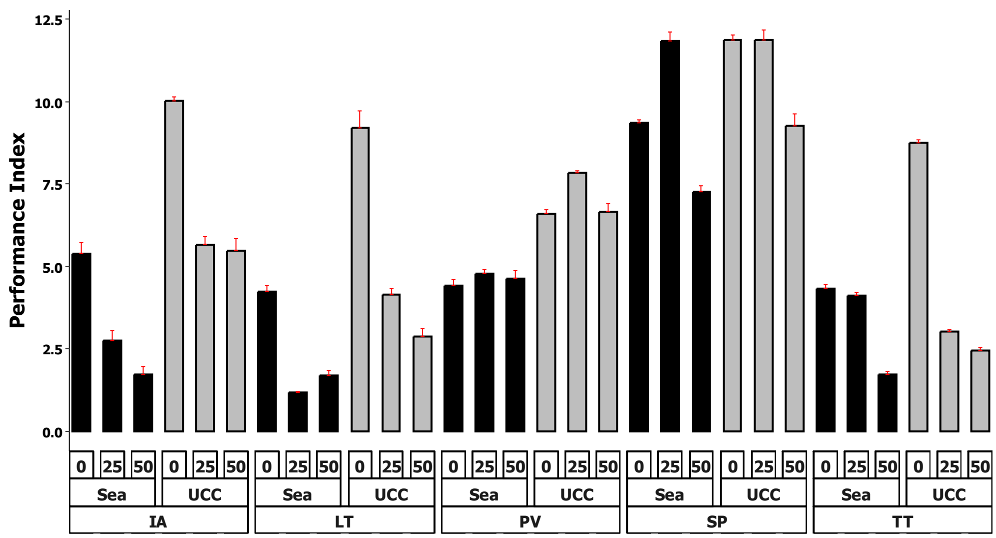


Figure 4.4: Effects of Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on Performance Index (PI) of the different Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

4.2.3 Effects of Salt Concentration and Soil Type on the Soil Properties

4.2.3.1 Soil pH

Soil pH was significantly affected by all salt concentrations, soil types and plant types as well as their interactions ($p < 0.001$). Sea sand (8.31 to 9.73) had a significantly higher soil pH than UCC soil (6 to 7.49). In Sea sand, *L. taraxacifoliar* (9.3) and *T. triangulare* (9.18) had the highest mean pH values followed by *P.*

Digitized by Sam Jonah Library

vaginatum (8.95) and *S. portulacastrum* (8.82) while *I. aquatica* (8.7) had lowest soil pH values whereas in UCC soil, a similar trend was observed with *L. taraxacifoliar*, *T. triangulare*, *P. vaginatum* and *I. aquatica* (7.03, 6.79, 6.51 and 6.5 respectively) recording higher. In contrast, *S. portulacastrum* (6.2) recorded the least soil pH value. Increasing salt concentrations resulted in increasing soil pH as the lowest soil pH value (6) was recorded at 0 dS/m while the highest (9.74) was recorded at 50 dS/m (Figure 4.5).

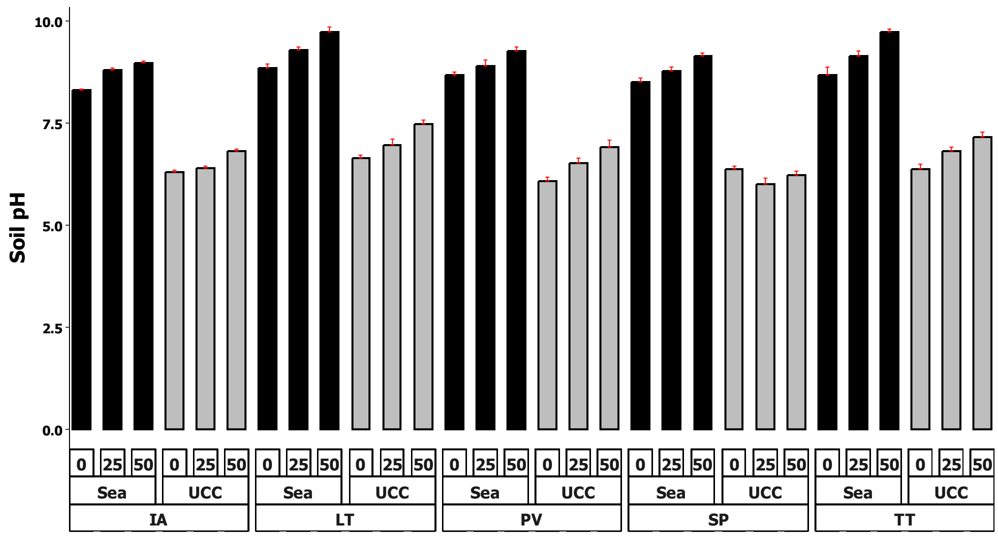


Figure 4.5: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Final Soil pH. Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

4.2.3.2 Soil Electrical Conductivity (EC)

Like soil pH, soil EC was also significantly affected by salt concentrations, soil types and plant types as well as their interactions ($p < 0.001$). The effects of the salt concentration were very obvious as no salt treatment (that is, 0 dS/m) had EC values between 0.04 and 0.48 dS/m, while salt treatment (25 and 50 dS/m) recorded

Digitized by Sam Jonah Library

values between 1.05 and 6.21 dS/m. Notably, increasing salt concentration resulted in increased soil EC values as 50 dS/m salt treatment recorded the highest EC values ranging between 2.24 and 6.21 dS/m and averaging 4.51 dS/m.

In terms of the plant species, *T. triangulare* (3.12 dS/m), *I. aquatica* (2.96 dS/m) and *L. taraxacifoliar* (2.9 dS/m) had higher mean soil EC values as compared to *P. vaginatum* (1.34 dS/m) and *S. portulacastrum* (1.18 dS/m). Also, sea sand (averaging 2.34 dS/m) generally resulted in higher EC values compared to UCC soil (2.25 dS/m) (Figure 4.6).

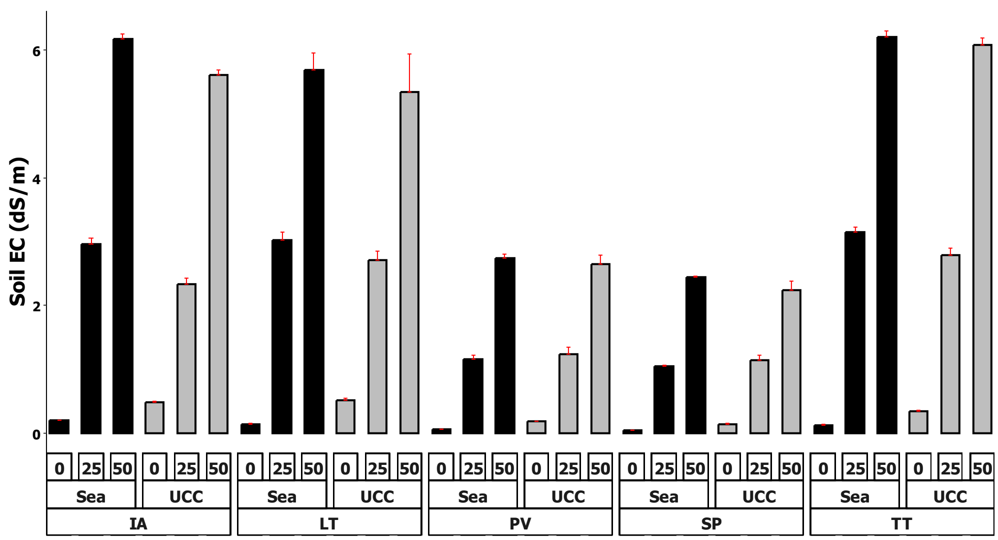


Figure 4.6: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Final Soil Electrical Conductivity (dS/m). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

4.2.3.3 Total Dissolved Solids (TDS)

The soil's total dissolved solids (TDS) was significantly ($p < 0.001$) affected by all treatment factors, that is, plant type, salt concentration and soil type, as well

Digitized by Sam Jonah Library

as the interactions between and among these factors. The final soil TDS had a similar trend as the final soil pH. The values ranged between 21.75 mg/L recorded on *S. portulacastrum* in sea sand at 0 dS/m salt treatment, and 2980.75 mg/L, recorded on *T. triangulare* in UCC soil at 50 dS/m salt treatment. For the soil types, UCC soil (averaging 1125.12 mg/L) had very high TDS values compared to Sea sand (686.18 mg/L) (Figure 4.7)

Total dissolved solids increased greatly with increasing salt concentrations, with 50 dS/m recording the highest TDS values across all plant and soil types. *Talinum triangulare*, *L. taraxacifoliar* and *I. aquatica* had higher TDS values at 50 dS/m (2980.75, 2761.75 and 2766.5 mg/L respectively) as compared to *P. vaginatum* and *S. portulacastrum* (1457.75 and 1247 mg/L respectively. Very low TDS values were recorded across all plant and soil types at 0 dS/m salt treatment, ranging from as low as 21.75 mg/L to 207 mg/L (Figure 4.7).

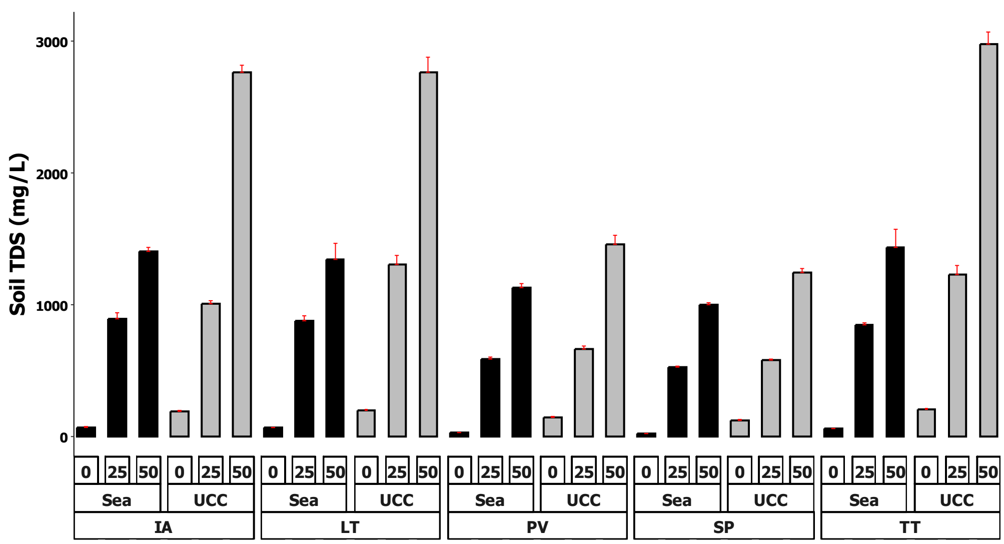


Figure 4.7: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Final Soil Total Dissolved Solids (mg/L). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*).

Digitized by Sam Jonah Library

4.2.3.4 Soil Sodium (Na) and Chlorine (Cl) Contents

The treatment factors and interactions significantly affected the final soil Na and Cl content ($p < 0.001$). Soil Na ranged from 0.33 to 3.41 mg/g, while Cl ranged from 0.13 to 1.98 mg/g. Increasing salt concentrations increased both soil Na and Cl contents. The 0 dS/m salt treatment resulted in soil Na content values between 0.22 and 0.46 mg/g, while the 25 and 50 dS/m treatments ranged from 0.47 to 3.41 mg/g (Figure 4.8). Also, Cl content values ranged between 0.13 and 0.45 mg/g at 0 dS/m salt treatment and between 0.20 and 1.98 mg/g at 25 and 50 dS/m salt treatments (Figure 4.9).

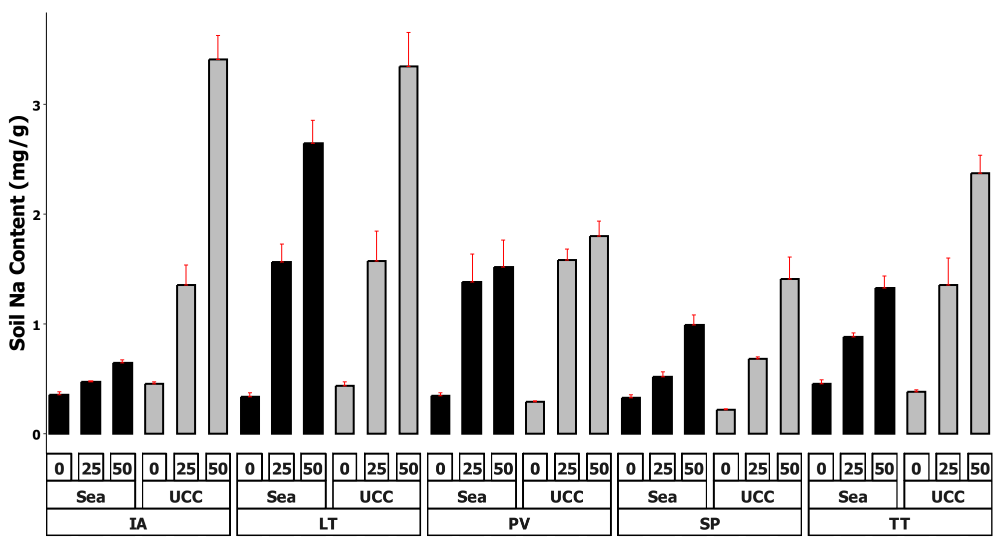


Figure 4.8: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Final Soil Sodium Content (mg/g). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

Final soil Na content was very low in *S. portulacastrum* (0.22 to 1.41 mg/g) and *P. vaginatum* (0.29 to 1.8 mg/g), while higher values were recorded for *L. taraxacifoliar* (0.34 to 3.34 mg/g) (Figure 4.8). Similarly, *L. taraxacifoliar* (0.15 to 1.2 mg/g) and *S. portulacastrum* (0.13 to 1.35 mg/g) recorded the lowest final soil Cl content while *I. aquatica* (0.26 to 1.76 mg/g) and *T. triangulare* (0.14 to 1.98 mg/g) recorded the highest (Figure 4.9). For the soil types, UCC soil (with a mean of 1.38 mg/g) had higher soil Na content compared to sea sand (0.92 mg/g). Likewise, soil Cl content in UCC soil averaged 0.96 mg/g, while it averaged 0.56 mg/g in sea sand.

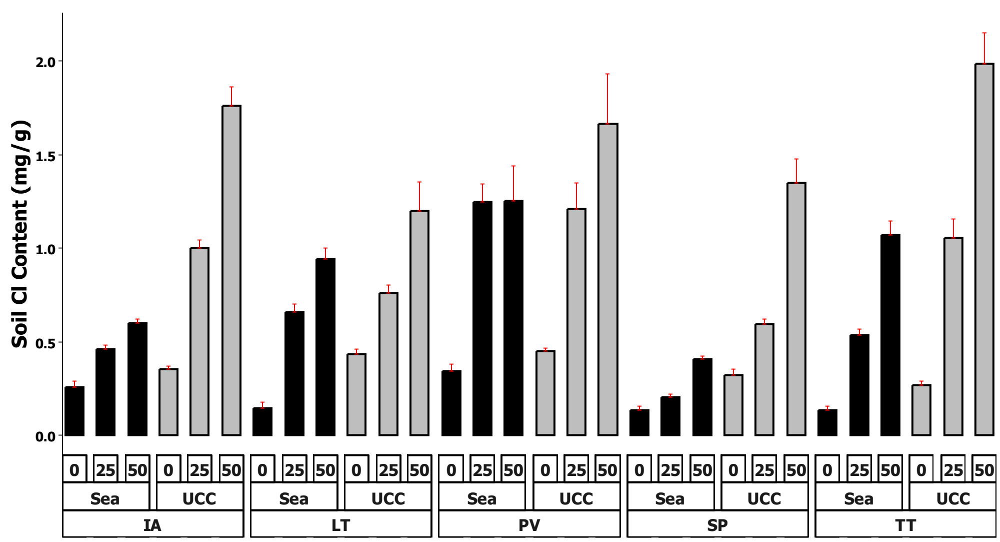


Figure 4.9: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on the Final Soil Chlorine Content (mg/g). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

4.2.4 Effects of Salt Concentration and Soil Type on Plant Tissue Na and Cl contents

4.2.4.1 Leaf Sodium (Na) and Chlorine (Cl) Content

The plant type ($p < 0.001$), soil type ($p < 0.01$ for Na and $p < 0.05$ for Cl) and salt concentration ($p < 0.001$) significantly affected the Na and Cl contents of the plant leaves. The interactions among these factors were also highly significant ($p < 0.001$). The mean leaf Na content was lower in sea sand (13.91 mg/g) compared to UCC soil (14.4 mg/g) (Figure 4.10). Similarly, for Cl content, sea sand (40.55 mg/g) recorded a lower average Cl content than UCC soil (41.7 mg/g) (Figure 4.11)

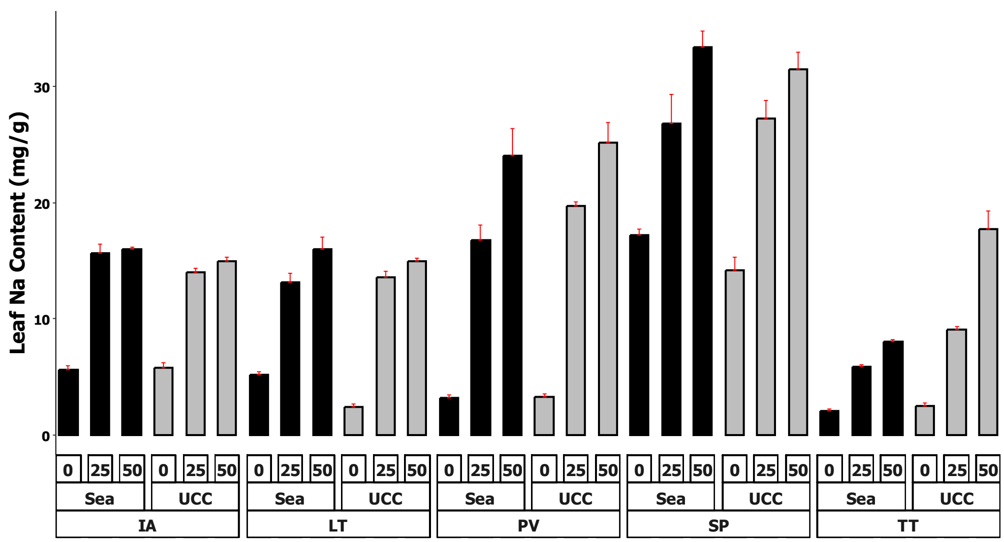


Figure 4.10: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on Leaf Sodium Content (mg/g). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

For the plant types, *S. portulacastrum* (25.03 mg/g) recorded the highest mean leaf Na content, followed by *P. vaginatum, I. aquatica, L. taraxacifoliar* and

Digitized by Sam Jonah Library

T. triangulare (15.35, 11.99, 10.87 and 7.53 mg/g respectively) (Figure 4.10). Also, the highest mean leaf Cl content was recorded by *L. taraxacifoliar* (48.36 mg/g) and *S. portulacastrum* (45.04 mg/g). In comparison, *T. triangulare* (28.41 mg/g), *P. vaginatum* (27.72 mg/g) and *I. aquatica* (26.71 mg/g) recorded lower values (Figure 4.11). Leaf Na and Cl content significantly increased with increasing salt concentrations, and the highest values (31.47 and 70.81 mg/g for Na and Cl contents, respectively) were recorded at 50 dS/m salt treatment.

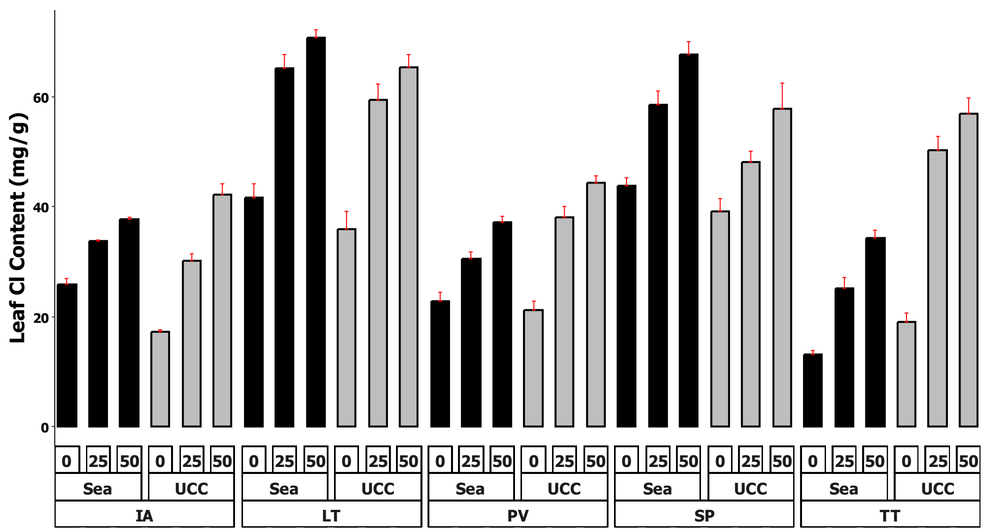


Figure 4.11: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on Leaf Chlorine Content (mg/g). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

4.2.4.2 Root Sodium (Na) and Chlorine (Cl) Content

Root Na and Cl content varied significantly among different plant types, soil types and salt concentrations and their various interactions ($p < 0.001$). The maximum root Na content recorded was 26.37 mg/g, and the minimum was 1.87

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

mg/g with a mean of 10.1 mg/g (Figure 4.12). Also, root Cl content averaged 29.38 mg/g, ranging from 55.98 mg/g to 5.29 mg/g (Figure 4.13).

Sesuvum portulacastrum (17.25 mg/g) recorded the highest average root Na content while *L. taraxacifoliar* (7.69 mg/g), *T. triangular* (7.43 mg/g) and *P. vaginatum* (7.38 mg/g) recorded very low root Na contents (Figure 4.12). Meanwhile, for root Cl content, *S. portulacastrum* (37.42 mg/g) and *I. aquatica* (34.51 mg/g) had higher root Cl content compared to *T. triangulare* (17.98 mg/g), which had the least root Cl content (Figure 4.13). Generally, sea sand (11.55 and 33.4 mg/g for root Na and Cl contents) resulted in higher root Cl contents than UCC soil (8.66 and 25.36 mg/g for root Na and Cl contents, respectively). The increase in salt concentrations led to significant increases in both root Na and Cl contents. Root Na content recorded over 200% increase due to increased salt concentration (from an average of 5.44 mg/g at 0 dS/m to 12.44 mg/g at 25 and 50 dS/m). Likewise, root Cl content also increased from 17.58 mg/g at 0 dS/m to 35.28 mg/g at 25 and 50 dS/m.

Digitized by Sam Jonah Library

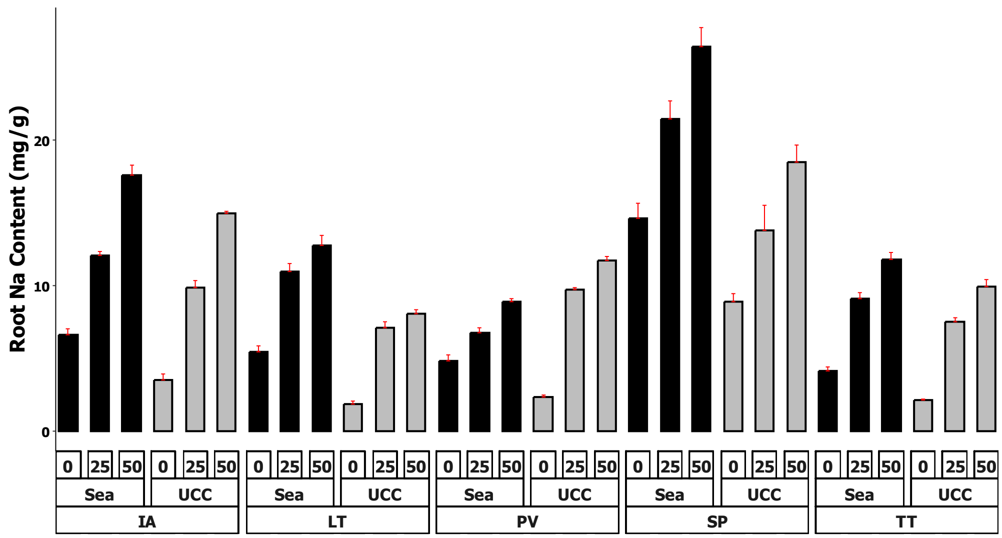


Figure 4.12: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on Root Sodium Content (mg/g). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

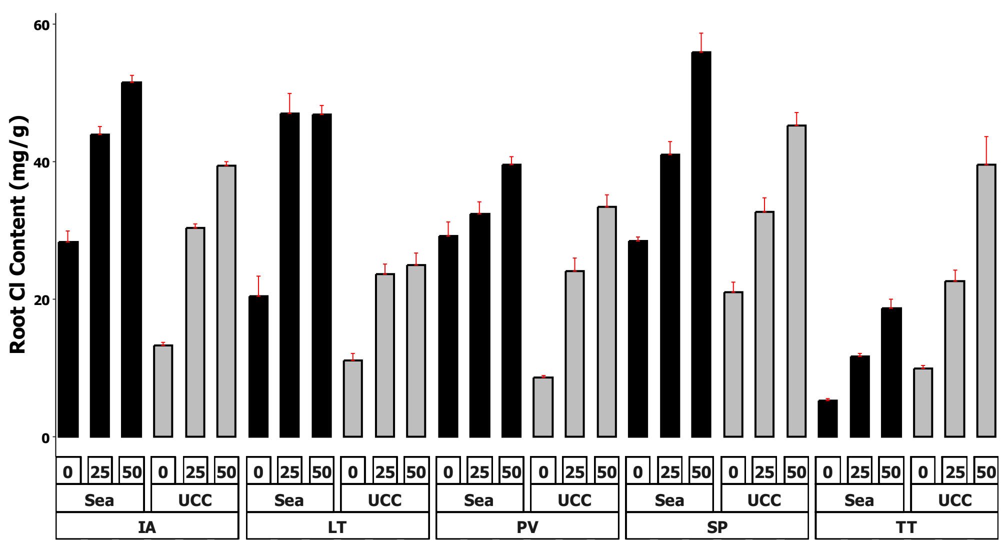


Figure 4.13: Effects of Plant type, Soil type (UCC, Sea) and Salt concentration (0, 25 and 50 dS/m) on Root Chlorine Content (mg/g). Plant types (IA- *I. aquatica,* LT- *L. taraxacifoliar,* PV- *P. vaginatum,* SV- *S. portulacastrum* and TT- *T. triangulare*). The salt concentrations applied were 0, 25 and 50 dS/m. Values are means of 4 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

4.2.5 Correlations Between Plant and Soil Parameters

The correlation analysis revealed significant associations between plant and soil parameters (Figure 4.14). There was a significantly strong and positive correlation between STDS and SEC ($r = 0.96$, $p < 0.001$) and strongly positive correlation between SPAD and PI ($r = 0.89$, $p < 0.001$); SCl and SNa ($r = 0.79$, $p < 0.001$); STDS and SNa ($r = 0.78$, $p < 0.001$); SEC and SNa ($r = 0.73$, $p < 0.001$); STDS and SCl ($r = 0.7$, $p < 0.001$). Also, significant and moderately positive correlations were observed between LCl and LNa ($r = 0.64$, $p < 0.001$); LCl and SNa ($r = 0.54$, $p < 0.001$); RCl and LNa ($r = 0.65$, $p < 0.001$); RCl and LCl ($r = 0.53$, $p < 0.001$), SEC and SCl ($r = 0.64$, $p < 0.001$); SpH and R:S ratio ($r = 0.61$, $p < 0.001$); Ltem and SCl ($r = 0.57$, $p < 0.001$); Ltem and SEC ($r = 0.56$, $p < 0.001$); Ltem and STDS ($r = 0.52$, $p < 0.001$); Fv.Fm and RHGR ($r = 0.58$, $p < 0.001$); PI and RHGR ($r = 0.58$, $p < 0.001$), PI and Fv.Fm ratio ($r = 0.66$, $p < 0.001$); SPAD and SDW ($r = 0.55$, $p < 0.001$); SPAD and RHGR ($r = 0.63$, $p < 0.001$) and SPAD and Fv.Fm ratio ($r = 0.62$, $p < 0.001$) (Figure 4.14).

On the other hand, some significant but negative relationships were also observed. The Fv/Fm ratio had a strongly negative correlation with SEC ($r = 0.8$, $p < 0.001$) and STDS ($r = 0.79$, $p < 0.001$). Also, a moderately negative correlation existed between R:S ratio and SDW ($r = 0.6$, $p < 0.001$), RCl and RDW ($r = 0.6$, $p < 0.001$), SEC and RHGR ($r = 0.67$, $p < 0.001$), STDS and RHGR ($r = 0.6$, $p < 0.001$), SpH and SDW ($r = 0.66$, $p < 0.001$). Again, Fv/Fm ratio recorded fairly negative correlations with SNa ($r = 0.54$, $p < 0.001$), SCl ($r = 0.56$, $p < 0.001$) and Ltem ($r = 0.56$, $p < 0.001$) while PI had similar correlations with R:S ratio ($r = 0.53$, $p < 0.001$), SEC ($r = 0.62$, $p < 0.001$), STDS ($r = 0.59$, $p < 0.001$) and SpH ($r =$

Digitized by Sam Jonah Library

0.55, $p < 0.001$). Similarly, SPAD had moderate correlations with R:S ratio ($r = 0.66$, $p < 0.001$), SEC ($r = 0.64$, $p < 0.001$), STDS ($r = 0.61$, $p < 0.001$) and SpH ($r = 0.52$, $p < 0.001$) (Figure 4.14).

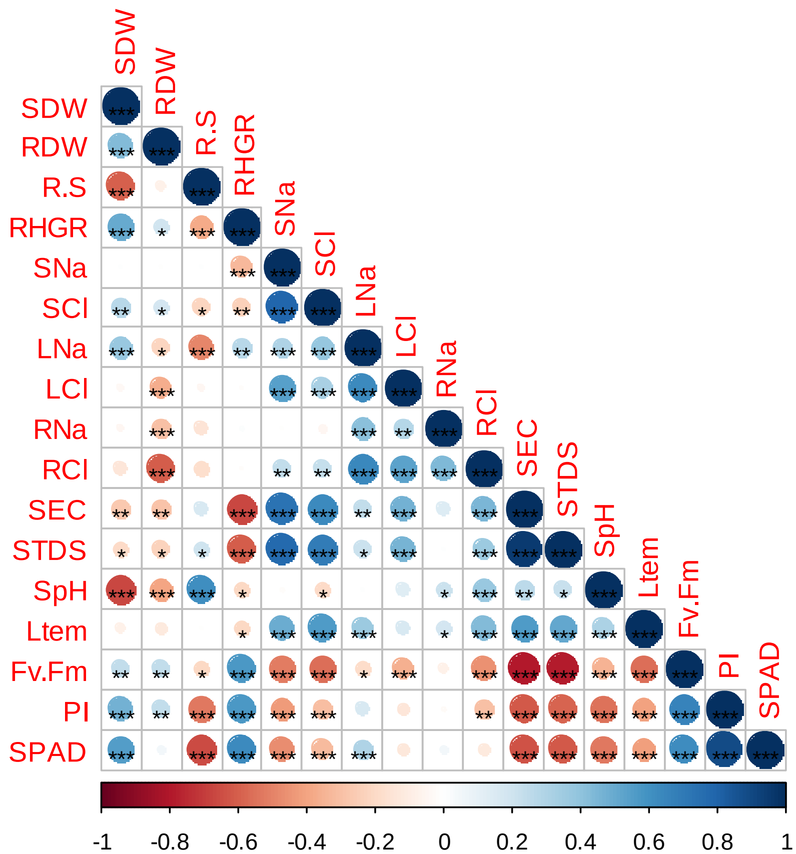


Figure 4.14: Correlation between plant biomass parameters (SDW- shoot dry weight, RDW- root dry weight, R.S- root to shoot ratio, RHGR- relative height growth rate), soil and tissue Na and Cl contents (SNa- soil Na content, SCl- soil Cl content, LNa- leaf Na content, LCl- leaf Cl content, RNa- root Na content, RCl- root Cl content), final soil chemical properties (SEC- soil electrical conductivity, STDS soil total dissolved solids, SpH- soil pH) and plant photosynthetic properties (Ltemp- leaf temperature, Fv. Fm- fv/fm ratio, PI- performance index, SPAD- SPAD readings). ***, **, * Correlation is significant at 0.001, 0.01 and 0.05 confidence levels, respectively.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

4.3 Assessing the Desalination Ability of *S. portulacastrum* in a Hydroponic System

4.3.1 Weather data

The weather data was taken over 11 weeks, from when the *S. portulacastrum* cuttings were nursed to the harvesting period, as shown in Figure 4.14. Generally, the ambient temperature ranged between 27.3°C and 29.9°C while that of the greenhouse was slightly higher, ranging from 28.7°C to 30.6°C. The mean ambient temperature was 28.52°C, while that of the greenhouse was 29.5°C. For the ambient temperature, slight fluctuations were observed over the weeks, with the highest temperature recorded in Week 2 (29.9°C) and the lowest in Week 7 (27.3°C). On the other hand, the highest greenhouse temperature was recorded in Week 4 (30.6°C), while the lowest was in Week 6 (29°C) (Figure 4.14).

The relative humidity also ranged from 67.9% to 74.4%. The greenhouse recorded slightly lower relative humidity levels, with a mean of 69.95%, whereas the mean ambient relative humidity was 72.39%. Ambient relative humidity varied between 70.3% (recorded in Week 7) and 74.4% (Week 4), whereas that of the greenhouse ranged from 67.9% (Week 6) to 72.9% (Week 2) (Figure 4.14).

Digitized by Sam Jonah Library

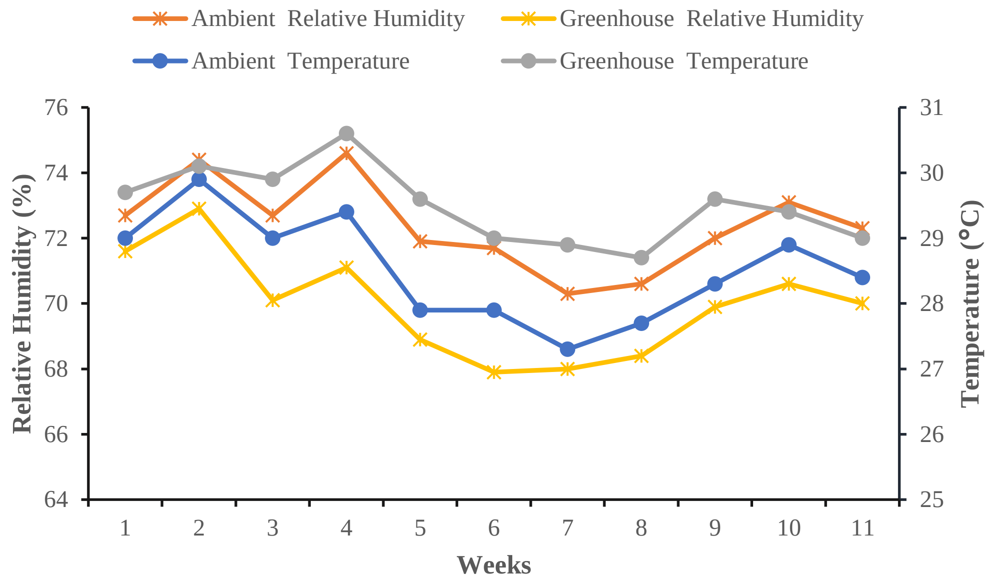


Figure 4.15: Ambient and greenhouse temperature and relative humidity of the study area over the 11 weeks of the study.

4.3.2 Changes in Water Quality Parameters of Salt Treated Hydroponic Solution

4.3.2.1 Water Quantity Lost

Generally, less water was lost from systems with higher salt concentrations. The water lost in 0 ds/m (totalling 164 L) treatment was the highest, followed by 25 dS/m (94 L) treatment and the lowest observed in the 50 dS/m (79 L) treatment (Figure 4.15).

For 0 dS/m salt treatment, the water loss increased gradually over the weeks, starting from 30 L in week 2 to 57 L by week 8. For the 25 dS/m salt treatment, an upward trend in water use was seen but at a lower rate than the 0 dS/m treatment. It ranged from 15 L in week 2 to 29 L in week 8. Similarly, the water used in the 50 dS/m salt treatment increased over the weeks but at a much lower rate than the 0 dS/m and 25 dS/m salt treatments. The values ranged from 10 L to 26 L from week

Digitized by Sam Jonah Library

2 to week 8. The most significant increase in water loss occurred between weeks 6 and 8 for 0 dS/m (35.7% increase) and between weeks 2 and 4 for 25 (53%) and 50 (80%) dS/m salt treatments (Figure 4.15).

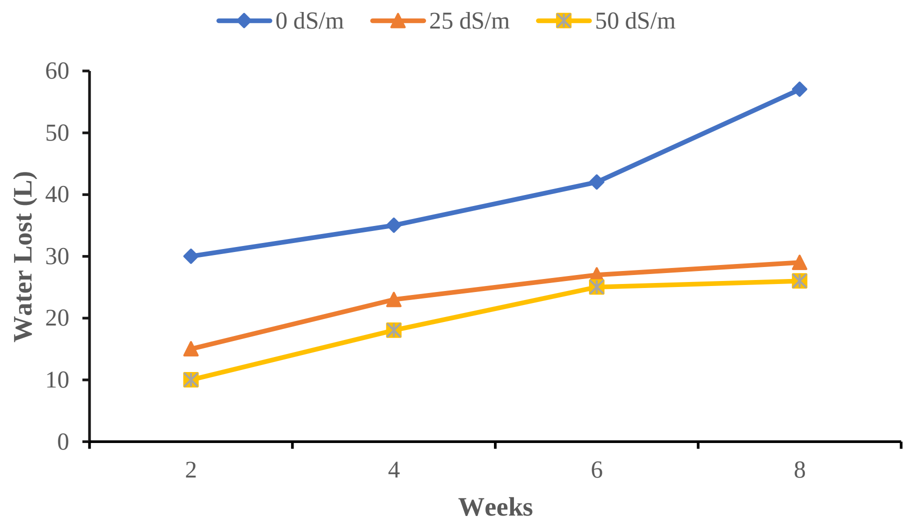


Figure 4.16: Water lost from the hydroponic system through evapotranspiration over eight weeks of monitoring.

4.3.2.2 Electrical Conductivity (EC)

The electrical conductivity values directly correlated with the salt concentration, with higher salt concentrations resulting in significantly higher EC values. The EC values for the 0 dS/m treatment remained relatively stable over the weeks, starting at 0.17 dS/m in week one and reaching 0.3 dS/m in week nine while averaging 0.23 dS/m. For 25 dS/m, the EC values consistently increased, from 7.42 dS/m to 38.7 dS/m from week 1 to week 9, averaging 27.13 dS/m. The EC for the 50 dS/m treatment also increased consistently from 12.07 dS/m in week 1 to 67.1 dS/m in week nine and averaged 54.17 (Figure 4.16 A).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

4.3.2.3 Total Dissolved Solids (TDS)

The TDS trend was very similar to that of the EC. The TDS values increased with increasing salt concentrations, with 50 dS/m (average of 27.1 ppt) salt treatment having the highest TDS, followed by 25 dS/m (13.55 ppt). The TDS values for 0 dS/m (0.09 to 0.15 ppt) treatment were the lowest and had an average of 0.12 ppt. Also, TDS values ranged from 12.07 ppt in week 1 to 67.1 ppt in week 9 for 50 dS/m treatment and 7.42 ppt to 38.9 ppt for 25 dS/m treatment (Figure 4.16 B).

4.3.2.4 pH

The pH values ranged between 6.66 and 8.16 and averaged 7.72, 7.2 and 7.14 for 0, 25 and 50 dS/m salt treatments, respectively. Generally, the 0 (from 7.33 to 7.24) and 50 (7.14 to 7.05) dS/m treatment showed a trend toward a decrease in pH, while the 25 (7.17 to 7.33) dS/m salt treatment exhibited the opposite. The pH values for 0 dS/m treatment showed variations over the weeks. It started from 7.33 in week one and went as high as 8.16 in week five before levelling at 7.24 in week 9. For 25 dS/m treatment, the pH values again exhibited some fluctuations, starting from 7.17 in week one and reaching as low as 6.66 in week seven before rising to 7.33 in week 9. The 50 dS/m treatment generally had lower values with minor fluctuations, starting from 7.14 in week 1, dropping to 6.77 in week seven and rising to 7.05 in week 9 (Figure 4.16 C).

Digitized by Sam Jonah Library

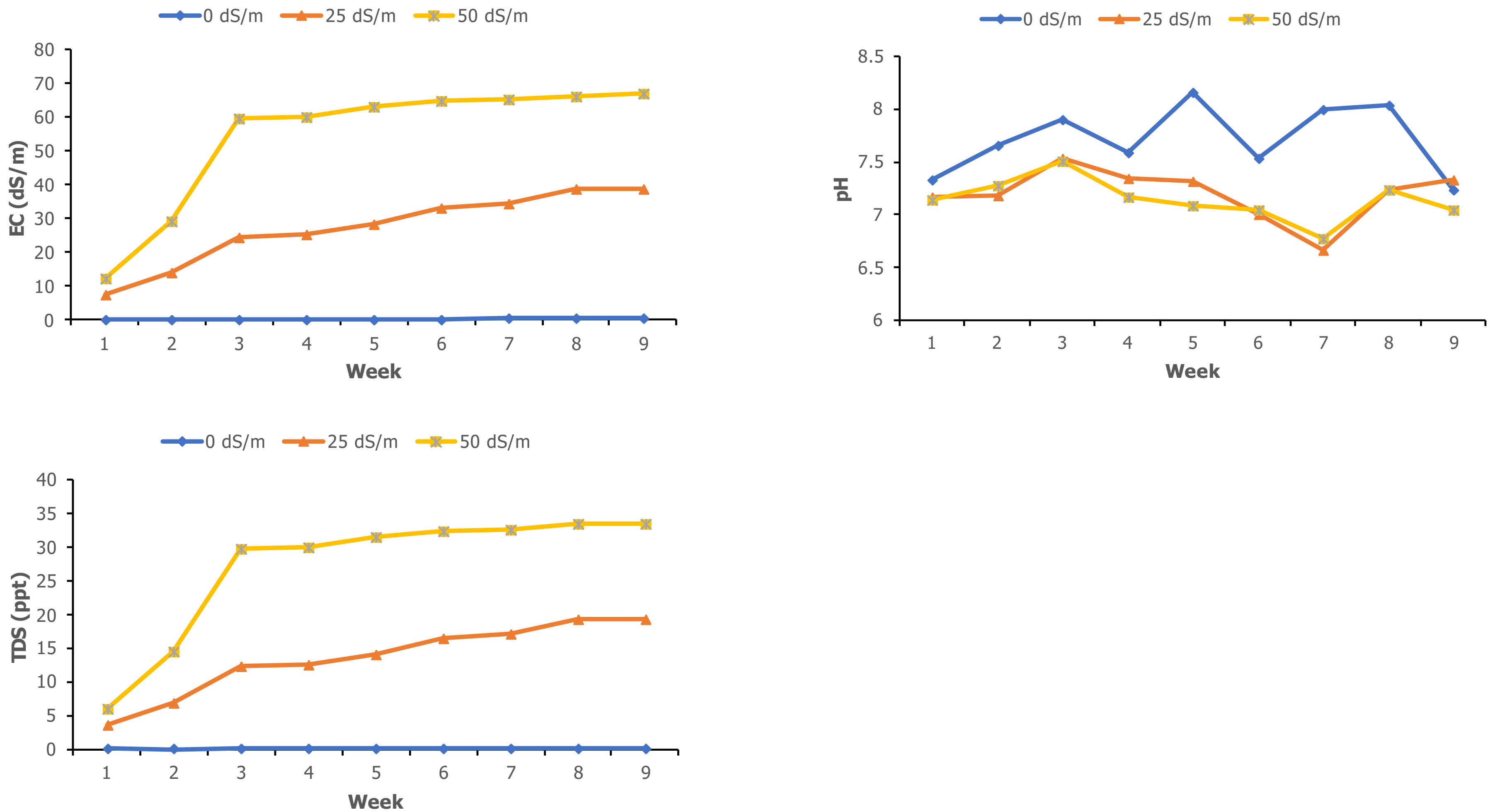


Figure 4.17: Changes in EC (electrical conductivity, dS/m), pH and TDS (total dissolved solids, ppt) of salt-treated hydropic solution (0, 25 and 50 dS/m) over the nine weeks of monitoring.

Digitized by Sam Jonah Library

4.3.3 Effects of Salt Treatment and Planting Distances on Plant Parameters

4.3.3.1 Plant Height

The salt concentrations, planting distances, and interactions significantly ($p < 0.001$) affected the plant height. The highest plant height was 30.6 cm, recorded for a salt concentration of 25 dS/m at a planting distance of 30 cm, while the lowest was 21 cm, recorded for a salt concentration of 0 dS/m and at 20 cm planting distance. Generally, the 25 dS/m salt treatment recorded higher plant heights (with a mean of 28.54 cm), ranging between 25.4 cm and 30.6 cm, whereas the 0 dS/m treatment, on the other hand, recorded the lowest plant heights (22.43 cm) between 21 cm to 24.1 cm. There were no significant differences in plant plant height for planting distances 15 and 20 cm (which averaged 24.42 and 24.44 cm, respectively) and for planting distnaces 30 and 40 cm, which averaged 26.36 and 26.42 cm, respectively (Figure 4.17).

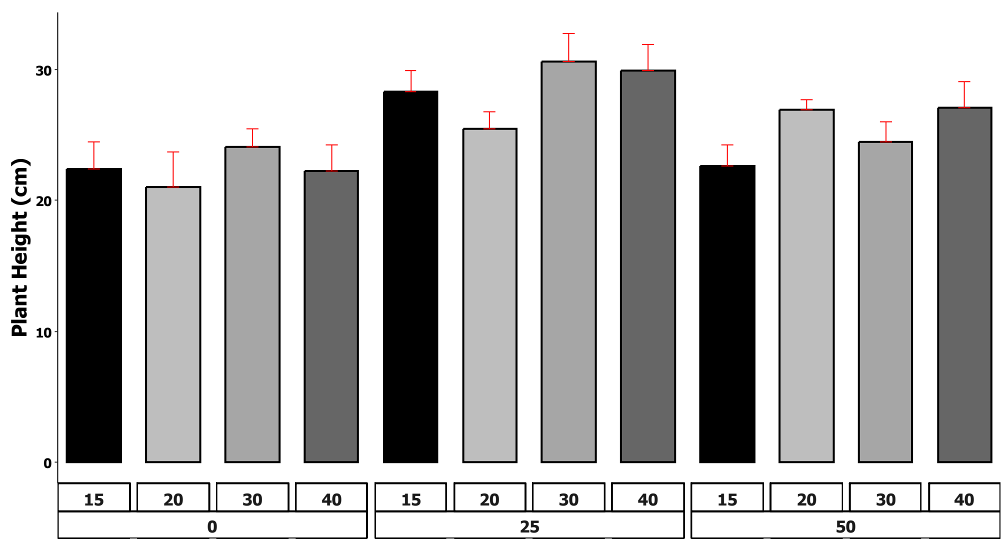


Figure 4.18: Effects of Salt concentration (0, 25 and 50 dS/m) and planting distances (15, 20, 30 and 40 cm) height of *S. portulacastrum.* Values are means of 6 replicates with standard deviation (SD).

Digitized by Sam Jonah Library

4.3.3.2 Shoot Fresh Weight

The main effects salt concentrations and planting distances, as well as their interactions, had highly significant ($p < 0.001$) effects on the shoot fresh weight of the plants. However, the effect of the block was slightly insignificant ($p = 0.052$), while the interaction among salt concentration, planting distances (PD) and the block was also insignificant ($p = 0.98$). The SFW ranged between 7.09 and 11.41 g and averaged 8.96 g. The highest SFW values (between 7.59 and 11.41 g with a mean of 9.86 g) were observed with the 25 dS/m treatment, followed by 50 dS/m treatment (7.09 and 9.87 g, mean = 8.75 g) and 0 dS/m treatment (7.58 and 8.83 g, mean = 8.26 g) recording the lowest SFW values. Also, SFW increased with increasing planting distances from a mean of 7.42 g recorded at 15 cm PD to 10.04 g at 40 cm PD (Table 4.6).

4.3.3.3 Shoot Dry Weight

Shoot dry weights varied significantly ($p < 0.001$) among the salt concentrations and planting distances, including their interaction. However, the block ($p = 0.055$) and the interactions among salt concentrations, planting distances and block ($p = 0.99$) were insignificant. The SDW varied between 1.37 and 2.12 g across all treatments and had a mean of 1.71 g. At 25 dS/m, higher SDW values between 1.39 and 212 g (mean = 1.82 g) were recorded, while lower values from 1.37 to 1.9 g (mean = 1.69 g) and 1.49 to 1.73 g (mean = 1.62 g) were recorded at 50 and 0 dS/m salt concentrations respectively. Also, increasing planting distances from 15 cm to 40 cm resulted in steady increases in SDW from 1.42 to 1.92 g (Table 4.6).

Digitized by Sam Jonah Library

4.3.3.4 Root Dry Weight

The main factors, salt concentrations and planting distances, significantly ($p < 0.001$) influenced the root dry weight. Their interaction was also highly significant ($p < 0.001$). Again, the effects of the block were significant ($p = 0.005$), while the three-way interaction among the three factors, salt, planting distances and block, was not significant ($p = 0.69$). The highest RDW (between 0.16 and 0.23 g, mean = 0.2 g) was observed at 50 dS/m, while the lowest ranged between 0.13 and 0.15 g (mean = 0.14 g) and was observed at 0 dS/m. Also, RDW tended to increase with increasing planting distances, starting from a mean of 0.15 g at 15 cm PD, 0.18 g at 20 cm PD, and ending at 0.2 g at 30 and 40 cm PD (Table 4.6).

4.3.3.5 Root-to-Shoot Ratio

The root-to-shoot ratio was significantly affected by the main effects of salt concentration ($p < 0.001$) and planting distances ($p < 0.001$). Their interactions also significantly affected the root-to-shoot ratio ($p < 0.001$). The blocking effect was also significant ($p = 0.005$), while the interactions among salt, planting distances and block were insignificant ($p = 0.69$). The root-to-shoot ratio averaged 0.11 g and ranged between 0.09 and 0.12 g.

Digitized by Sam Jonah Library

Table 4.6: Effects of salt concentrations (0, 25 and 50 dS/m) and planting distances (15, 20, 30 and 40 cm) on shoot fresh and dry weight, root dry weight and root to shoot ratio of *Sesuvium portulacastrum*

PD	Shoot Fresh Weight (g)			Shoot Dry Weight (g)		
	0	25	50	0	25	50
15	7.58 ± 0.21	7.59 ± 0.29	7.09 ± 0.17	1.49 ± 0.04	1.39 ± 0.06	1.37 ± 0.03
20	7.93 ± 0.09	9.33 ± 0.42	8.59 ± 0.30	1.56 ± 0.02	1.72 ± 0.08	1.66 ± 0.06
30	8.68 ± 0.34	11.12 ± 0.31	9.45 ± 0.23	1.70 ± 0.06	2.06 ± 0.06	1.82 ± 0.04
40	8.83 ± 0.22	11.41 ± 0.38	9.87 ± 0.12	1.73 ± 0.04	2.12 ± 0.07	1.90 ± 0.02

PD	Root Dry Weight (g)			Root: Shoot Ratio		
	0	25	50	0	25	50
15	0.13 ± 0.01	0.15 ± 0.01	0.16 ± 0.01	0.09 ± 0.001	0.11 ± 0.001	0.12 ± 0.000
20	0.14 ± 0.01	0.19 ± 0.01	0.20 ± 0.01	0.09 ± 0.001	0.11 ± 0.001	0.12 ± 0.001
30	0.15 ± 0.01	0.22 ± 0.01	0.22 ± 0.01	0.09 ± 0.001	0.11 ± 0.001	0.12 ± 0.002
40	0.15 ± 0.01	0.23 ± 0.01	0.23 ± 0.01	0.09 ± 0.001	0.11 ± 0.001	0.12 ± 0.001

Values are means of 6 replicates with standard deviation (SD). PD – Planting distances.

Digitized by Sam Jonah Library

Within each of the three salt treatments, the effects of the planting distances remained insignificant while it increased slightly with increasing salt concentrations (0.09 for 0 dS/m, 0.11 for 25 dS/m and 0.12 for 50 dS/m). The 50 dS/m salt treatment had the highest root-to-shoot ratio (0.12), while the 0 dS/m had the lowest (0.09). However, there was no significant difference between the 25 (0.11 g) and 50 (0.12 g) dS/m treatment (Table 4.6).

4.3.4 Correlations Between Plant Parameters

Significant correlations were observed between the measured plant biomass parameters (Figure 4.14). A perfectly positive correlation was observed between SFW and SDW ($r = 0.99$, $p < 0.001$). RDW had a positive and strong correlation with SFW ($r = 0.82$, $p < 0.001$), SDW ($r = 0.82$, $p < 0.001$) and root-to-shoot ratio ($r = 0.75$, $p < 0.001$). A moderately positive correlation existed between plant height and SFW, SDW and RDW ($r = 0.61$, 0.53 and 0.61 respectively, $p < 0.001$) as well as between stem girth and R.S. ratio ($r = 0.55$, $p < 0.001$). Also, a weak but positive correlation was observed between stem girth and RDW ($r = 0.46$, $p < 0.001$) and between height and R.S. ratio ($r = 0.42$, $p < 0.001$) (Figure 4.18).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

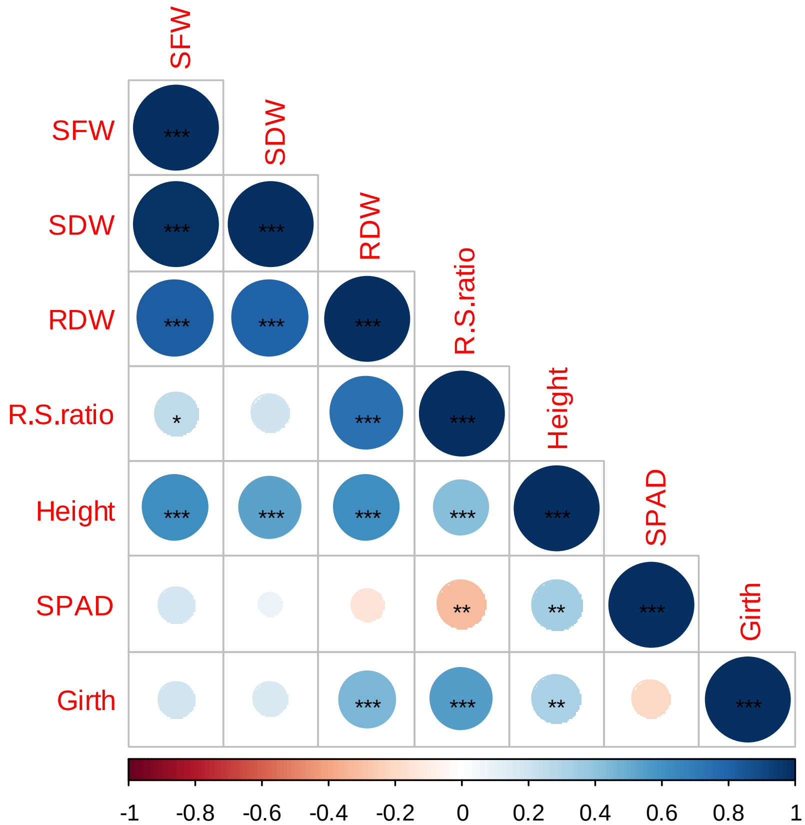


Figure 4.19: Correlation between plant biomass parameters (SDW- shoot dry weight, RDW- root dry weight, R.S- root to shoot ratio, plant height, stem girth), and SPAD readings. ***, **, * Correlation is significant at 0.001, 0.01 and 0.05 confidence levels respectively.

Digitized by Sam Jonah Library

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Diversity of Halophytes in Cape Coast, Ghana

The diversity of plant types and growth habits among the identified halophytes in Ghana showcases the remarkable adaptability of halophytes to saline environments. This diversity is crucial for these areas' overall resilience and ecological stability. The various herbaceous plants, shrubs, succulents, climbers and trees highlight the richness of plant life in Ghana's saline habitats.

Among the halophytes identified in this study, *Sesuvium portulacastrum*, *Paspalum vaginatum*, *Indigofera spicata* and *Cyperus ligularis* share similarities with those documented by Swaine *et al.* (1979) who studied the zonation of halophytes along the coast in Ghana. It is important to note that Swaine *et al.*'s research focused on the coastal region west of Accra, precisely Bortiano, while the current research was conducted in Cape Coast. This signifies the resilience and adaptability of these halophyte species across diverse coastal environments and periods, as indicated by Wungrampha *et al.* (2021), who found that halophytes evolve several anatomical, physiological, molecular and structural changes to undergo their usual molecular and physiological processes even under increased salt environments. It also confirms the works of Flowers and Colmer (2008) and Grigore (2021), who reported that halophytes employ different adaptations, including biochemical, physiological, molecular and anatomical changes that help them cope with salt stress conditions.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

The halophytes identified belong to various families, including Amaranthaceae, Convolvulaceae, Solanaceae, Fabaceae, Scrophulariaceae, Cyperaceae, Asteraceae, Euphorbiaceae and Crassulaceae. They exhibit a range of growth habits, from herbaceous plants like *Amaranth spp.* and *Cyperus ligularis* to shrubs like *Capraria biflora* and succulents like *Sesuvium portulacastrum* and *Sansevieria masoniana*. Also, in terms of lifecycles, annuals such as *Ipomoea asarifolia*, *Lactuca taraxacifolia*, and perennials, including *Paspalum vaginatum* and *Cocos nucifera* were identified. These growth habits and lifecycles reflect the various ecological strategies employed by these plants in adapting to their environments and confirm the works of Jefferies *et al.* (1979), who studied and observed varied growth habits and lifecycles in halophytes and stressed their role in conferring salt stress tolerance in halophytes.

5.2 Potential Uses or Importance of Identified Halophytes

The identified halophytes hold significant economic, ecological, and cultural importance. Several species, such as *Amaranth spp.* (Aderibigbe *et al.*, 2022), *Capraria biflora* (Vasconcellos *et al.*, 2005) and *Euphorbia albomarginata* (Rojas *et al.*, 2010) have documented uses in traditional medicine, while others serve culinary purposes, like the edible leaves of *Sesuvium portulacastrum* (Lokhande *et al.*, 2013) and *Talinum triangulare* (Pavithra *et al.*, 2017) as well as the fruits of *Physalis spp.* (Daunay *et al.*, 2007) and *Cocos nucifera* (Pham, 2016). Ornamental value is evident in plants like *Sansevieria masoniana* (Chahinian 2000) and *Kalanchoe daigremontiana* (Navarrete *et al.*, 2021).

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

The diversity of growth habits and lifecycles observed in the identified halophytes contributes to the ecological resilience of coastal ecosystems. Plants like *Opuntia spp.* (Ciriminna *et al.*, 2019), *Ipomoea asarifolia* (Albuquerque et al, 2007), *Sesuvium portulacastrum* (He *et al.*, 2022) *Cyperus ligularis* (Casierra-Martínez *et al.*, 2017) and *Canavalia rosea* (Lin *et al.*, 2021) play crucial roles in ground cover, erosion control and soil stabilization, while others including *Ipomoea aquatica* (Rai and Sinha, 2001), *Pedalium murex* (Tripathi *et al.*, 2021) and *Sesuvium portulacastrum* (He *et al.*, 2022) are valuable for phytoremediation and restoration of degraded soils. Also, the adaptation of certain species, like *Paspalum vaginatum* (Fabbri *et al.*, 2016), for turfgrass and forage for livestock and *Indigofera spicata* (Mouafon *et al.*, 2021), for soil improvement and forage for livestock, highlight the diverse potentials these halophytes possess in sustainable land management and ecological restoration.

Understanding and conserving this diversity is essential for sustainable land use and biodiversity conservation efforts. The different growth habits reflect the evolutionary strategies of these plants and provide opportunities for various applications. These findings reveal the diverse and underexploited nature of halophytes in Ghana. Harnessing the potential of these halophytes can contribute significantly to Ghana's local economies and environmental conservation initiatives. Further research and conservation efforts should be aimed at preserving and exploiting this rich diversity of halophytic plant types and their various qualities.

Digitized by Sam Jonah Library

5.3 Assessing the Salt Tolerance Levels and Remediation Abilities of Selected Halophytes

Based on their importance in human and animal nutrition, short lifecycle and simple propagation methods, *T. triangulare*, *I. aquatica*, *L. taraxacifolia*, *S. portulacastrum* and *P. vaginatum*, were selected for a greenhouse experiment to study their salt tolerance and remediation abilities.

5.3.1 Effects of Soil Type on Growth and Biomass Accumulation of Selected Halophytes

From the results obtained in this study, the soil type played a crucial role in most of the measured parameters. Arable soil generally promoted the growth and resilience of the halophytes compared to sea sand. However, general knowledge suggests that halophytes thrive in sea sand due to their inherent salt tolerance. This result may be attributed to soil composition, drainage, or nutrient availability variations. As highlighted by Morgan, (2013), variations in soil properties such as texture, organic matter content and nutrient levels can profoundly impact plant performance and productivity. Arable soil, characterized by its likely superior drainage, nutrient retention, and soil structure, may have provided a more conducive growth environment and nutrition for halophytes than sea sand, which contains relatively lower quantities of soil nutrients and very poor structure. However, arable soil resulted in a significantly lower R:S ratio than sea sand. This result could be attributed to the poor nutrient composition of the sea sand, compelling plants to allocate more resources to the roots to scavenge for water and nutrients. This phenomenon aligns with the findings of Wang *et al.* (2023) and Hermans *et al.* (2021), who highlighted that under conditions of below-ground

Digitized by Sam Jonah Library

resource deficit, plants tend to allocate greater portions of biomass to their roots in search of essential resources.

The study's results also indicate the significant influence of soil types and salt concentrations on the relative height growth rates of the various halophytes. *Paspalum vaginatum* and *Sesuvium portulacastrum* demonstrated the highest relative plant height growth rate at increased salt concentrations, suggesting a certain level of tolerance or even potential benefits for these species under elevated salinity conditions. This finding confirms Slama *et al.*'s (2006, 2007a, 2008) works, who reported increased growth rates in *Sesuvium portulacastrum* when subjected to low salt concentrations. However, it contradicts the work of Shahba *et al.* (2012), whose research indicated a reduced plant height in *Paspalum vaginatum* under salinity stress attributed to increased root mass.

On the contrary, *Talinum triangulare*, *Ipomoea aquatica* and *Lactuca taraxacifolia* exhibited lower RHGR at increasing salt concentrations, indicating lower tolerance to high salt concentrations. This observation suggests that these species may have reached their threshold for salt tolerance at the 25 and 50 dS/m salt treatments, beyond which their growth is significantly inhibited. It is plausible that the excessively high salt concentrations in the soil surpassed the tolerance mechanisms of these halophytes, leading to compromised growth rates. These results confirm the findings of Shrivastava and Kumar (2015), Jumberi *et al.* (2002), Hasanuzzaman *et al.* (2009) and Sakr *et al.* (2015), who have reported similar trends in various plants and attributed these changes to ion toxicity, osmotic stress and nutrient imbalances.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

The results revealed significant salt concentrations and soil types effects on all plant species' shoot dry weight (SDW) and root dry weight (RDW). The increase in salt concentration generally led to a reduction in both SDW and RDW in *T. triangulare*, *I. aquatica* and *L. taraxacifolia*, revealing the negative impact of increased salinity on biomass accumulation for these species. This finding aligns with previous research indicating the detrimental effects of salt stress on plant growth and productivity (Amirjani, 2011; Garg *et al.,* 2006; De Pascal *et al.,* 2003).

However, *P. vaginatum* and *S. portulacastrum's* response to increasing salt concentrations was interesting. These halophytes exhibited an increase in SDW with higher salt concentrations, challenging the notion of salt stress generally limiting biomass accumulation in plants. This finding is consistent with the work of Lokhande *et al.* (2013), who reported increased biomass accumulation in *S. portulacastrum* at salinity conditions between 100–400 mM NaCl and nutrient-deprived settings, indicating the plant's capacity to adapt to and even benefit from elevated salinity levels. Contrastingly, while the RDW of *S. portulacastrum* decreased with higher salt concentrations, indicating the negative effects of salinity stress on roots growth, *P. vaginatum* demonstrated increased RDW, suggesting a potential strategy for adjusting to water deficit under saline conditions. These findings are consistent with previous works reporting similar responses in other plant species subjected to high salt treatments (Slama *et al.,* 2006, 2007a, 2008; Yildirim and Güvenç, 2006; Shahba *et al.*, 2012). The discrepancies observed in the biomass responses of different plant species to salt stress may be attributed to various factors, including the frequency and duration of salt treatment applications.

Digitized by Sam Jonah Library

Unlike previous studies involving periodic salt treatments, the salt treatment in this experiment was applied only once, potentially influencing the plant's physiological responses.

The root-to-shoot (R:S) ratio was also significantly influenced by soil types and salt concentrations, stressing the plasticity of halophyte root-shoot allocation strategies in response to environmental conditions. *Talinum triangulare* and *L. taraxacifolia* displayed very high R:S ratios, suggesting a preference for allocating biomass towards root development. In contrast, *S. portulacastrum* had the lowest R:S ratio, indicating the allocation of more biomass to shoots than roots. This could be attributed to the fact that *T. triangulare* and *L. taraxacifolia* possess taproot systems, which weigh higher than the fibrous roots of *S. portulacastrum*. This finding contradicts the finding of Akman (2020), who worked on tap-rooted plants including *Pisum sativum*, *Carthamus tinctorius* and *Vicia pannonica* and fibrous-rooted plants including *Secale cereale*, *Hordeum vulgare* and *Avena sativa*. They found that, the fibrous-rooted plants have higher root-to-shoot ratios than the tap-rooted plants.

The observed variability in biomass accumulation among these halophyte species under different soil and salinity conditions holds significance for selecting suitable candidates for cultivation in saline environments. The biomass accumulation of *Paspalum vaginatum* and *S. portulacastrum* may be exploited as options for sustainable land management strategies, including soil improvement and ecological restoration.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

5.3.2 Physiological Response of Selected Halophytes Under Salt Stress

The study's results revealed a consistent trend where tissue water content (TWC) generally decreased with increasing salt concentrations. This aligns with expectations, as higher salinity typically leads to reduced water uptake by plants (Lu and Fricke, 2023). However, *S. portulacastrum* exhibited a contrasting trend, particularly at 25 dS/m salt concentration, where TWC was higher than 0 and 50 dS/m salt treatments. This observation suggests that the tolerance of *S. portulacastrum* to salt stress could be attributed to the succulence of its leaves. The succulent nature of its leaves allows *S. portulacastrum* to retain and accumulate water, potentially enabling it to counteract the effects of increased salt concentrations in its tissues. This finding is consistent with the findings of Vyas *et al.* (2023) and Khan *et al.* (2000), who highlighted succulence as a salt tolerance mechanism in other halophytes, including *Suaeda nudiflora*, *Suaeda fruticose* and *Salicornia brachiate*. Although *T. triangulare* also possesses succulent leaves, it was observed that the salt concentrations at 25 and 50 dS/m reduced its TWC. This finding may be attributed to the limited salt tolerance of *T. triangulare*, as the plant has been reported to tolerate salt concentrations lower than 0.5% NaCl as a miohalophyte (Bamidele *et al.*, 2007; Chapman, 1942).

The study observed a trend where leaf temperature increased with increasing salt concentrations across all the plant species, revealing the salinity stress's detrimental effects on the halophytes' leaves. The increased leaf temperature suggests a potential disruption in regulating leaf temperature homeostasis in response to salt stress. This result confirms the previous work of Orzechowska *et*

Digitized by Sam Jonah Library

al. (2021), who noted that salt-stressed plants typically exhibit increased leaf temperature due to stomatal closure to reduce water loss under such conditions.

Also, the study found variations in the fv/fm ratios among plant species and salt concentrations, with increasing salt concentrations leading to decreased fv/fm ratios. The decrease in fv/fm ratios suggests a reduction in the photochemical efficiency of plants under salt stress conditions. This finding is consistent with the discoveries of Saddiq *et al.* (2021), Hnilickova *et al.* (2021), Nabati *et al.* (2021) and Shin *et al.* (2021), who reported decreased fv/fm ratios resulting in decreased photochemical efficiency in various plants species under salt stress. The reduction in fv/fm ratios indicates impairment in the ability of plants to efficiently use light energy for photosynthesis, potentially leading to decreased growth and productivity. While halophytes are typically associated with salt tolerance, the observed negative responses of the halophytes to the salt stress suggest that halophytes exhibit varied levels of salt tolerance depending on factors such as the type of halophyte, the severity and duration of the salt stress, and conditions of the growth environment.

Furthermore, the study observed a consistent trend where SPAD values decreased with increasing salt concentrations across the plant types, which is in line with previous research by Sepehr and Ghorbanli (2006), Albassam (2001) and Hnilickova *et al.* (2021), who reported similar decreases in SPAD readings in various plants under salt stress conditions. The decline in SPAD values reflects a reduced chlorophyll content, indicating potential impairment in photosynthetic efficiency due to salinity stress. Despite the adverse salt conditions, *S.*

Digitized by Sam Jonah Library

portulacastrum consistently exhibited higher SPAD values than other plant types. This suggests that *S. portulacastrum* possesses inherently high chlorophyll content, which may contribute to its ability to maintain photosynthetic activity under saline conditions.

In addition to SPAD values, the plants' performance index (PI) varied significantly among the salt treatments. Generally, the PI decreased with increasing salt concentrations, which is consistent with the findings by Giorio and Sellami (2021) and Saddiq *et al.* (2021) in rice and wheat plants under salt stress. The reduction in PI reflects compromised photosynthetic performance and overall plant health in response to salinity stress. However, it is noteworthy that *S. portulacastrum* and *P. vaginatum* had increased SPAD values at 25 dS/m salt treatment, indicating a potential enhancement in photosynthetic efficiency under moderate salt stress conditions.

5.3.3 Response of Soil Salinity Parameters to Selected Halophytes Under Salt Stress

Soil pH varied significantly among the plant types and showed an increasing trend with increasing salt concentrations. Soil electrical conductivity (EC) and total dissolved solids (TDS) also varied among the plant species but increased exponentially with increasing salt concentrations. This observation reinforces that soil EC and TDS are reliable proxies for soil salt content, as highlighted by Visconti and Paz (2016). For all the measured parameters, *P. vaginatum* and *S. portulacastrum* showed great potential for use in desalination schemes. *Paspalum*

Digitized by Sam Jonah Library

vaginatum and *S. portulacastrum* exhibited an interesting phenomenon where soil EC and TDS levels were relatively lower despite increasing salt concentrations.

Also, these halophytes displayed very low soil Na and Cl levels even at increasing salt concentrations, signifying their extraordinary ability to reduce the accumulation of toxic Na and Cl ions in salt-affected soils. Furthermore, *P. vaginatum* and *S. portulacastrum* showed phenomenal Na uptake into their leaves, suggesting an increased tolerance to salt stress, probably through mechanisms such as ion sequestration, antioxidant defence mechanisms, ion homeostasis and stomatal conductance (Bose *et al.,* 2014; Munns, 2005; Suriani *et al.,* 2019; Gururani *et al.,* 2015). The significant accumulation of Na and Cl ions in the roots of *S. portulacastrum* further highlights its salt exclusion mechanism, reducing permeability to sodium ions at their root surface content. This finding is consistent with Matsushita and Matoh (1991), who demonstrated increased Na^+ and Cl^- concentrations in the roots of salt-tolerant reed plants.

These results validate the exceptional desalination potential of these halophytic plants, rendering them suitable for desalination programmes aimed at reclaiming saline soils and water. These findings are coherent with the works of Hue *et al.* (2002), Wang *et al.* (2022) and Lokhande *et al.* (2013), which demonstrated the remediation abilities of *P. vaginatum* and *S. portulacastrum*, especially in salt-affected environments. The special qualities of these halophytes may be attributed to enhanced Ca^{2+} signalling, osmotic adjustments, salt compartmentalization, as well as other salt tolerance mechanisms, as highlighted

Digitized by Sam Jonah Library

by previous studies (Wu *et al.*, 2020; Feng *et al.*, 2014; Peng *et al.*, 2016; Flowers and Colmer, 2008).

5.3.4 Relationship between measured parameters

Correlation analysis showed several significant relationships between various soil properties and plant parameters. Specifically, there was a significantly positive correlation between total dissolved solids (TDS) and EC, soil Cl and Na content, SPAD values and PI, soil Cl and Na content, and EC and soil Na content. This suggests that as one parameter increases, the other has a corresponding increase, and vice versa. These results support previous findings emphasising the positive relationships between soil properties and plant parameters. For instance, a positive correlation has been reported between soil EC and TDS (Rusydi, 2018), EC and Na content (Singh *et al.*, 2010), and Na content and Cl content (Obiefuna and Orazulike, 2011). On the other hand, a significant negative relationship was observed between fv/fm and EC and between fv/fm and TDS, indicating an inverse relationship between this plant parameter and the soil properties. This implies that as soil EC and TDS increase, the fv/fm of the plants tend to reduce, indicating a decrease in photosynthetic efficiency under high soil EC and TDS contents.

Based on the findings of this study, both *P. vaginatum* and *S. portulacastrum* demonstrated significant tolerance and remediation abilities, specifically at the 25 dS/m salt treatment. However, *S. portulacastrum* was chosen for further study and application in the context of desalination efforts. *Sesuvium portulacastrum* demonstrated exceptional capabilities in salt uptake from the soil, a critical characteristic for the desalination objective of the study. This plant species

Digitized by Sam Jonah Library

exhibited remarkable efficiency in absorbing Na and Cl ions from the soil, substantially reducing soil Na and Cl contents. Furthermore, *S. portulacastrum* demonstrated robust biomass accumulation under the salt stress conditions evaluated in the study. This attribute enhances its suitability for desalination, as it can effectively provide biomass harvested for food due to its wide use as a vegetable plant.

5.4 Assessing the Desalination Ability of *S. portulacastrum* in a Hydroponic System

5.4.1 Ambient and Greenhouse Temperatures and Relative Humidities

Generally, the greenhouse temperature was slightly above that of the ambient, which could likely be attributed to the greenhouse's design and environmental factors within the enclosed space. Greenhouses are typically designed to trap heat from sunlight, creating a warmer environment conducive to plant growth (Moore 2024). Conversely, the lower relative humidity observed within the greenhouse compared to ambient conditions may be due to the transpiration process of plants within the greenhouse, coupled with the heating effects of sunlight (Katsoulas and Stanghellini 2019). These processes may contribute to the lower relative humidity by promoting evaporation and moisture loss from plant surfaces and the surrounding environment.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

5.4.2 Desalination Ability of *Sesuvium portulacastrum*

Generally, higher salt concentrations corresponded to reduced water loss from the hydroponic system, which aligns with expectations and suggests a decreased transpiration rate in salt-stressed environments. The water loss of 164 L, 94 L and 79 L through evapotranspiration at salt concentrations of 0 dS/m, 25 dS/m and 50 dS/m, respectively, indicate a reduced trend in water loss with increasing salt concentrations. This phenomenon can be attributed to the physiological response of plants to high salt concentrations, which often results in reduced water uptake and transpiration rates. Salt stress interferes with the plant's ability to regulate water uptake, leading to a decrease in hydraulic conductivity and subsequent reduction in transpiration rates (Lu and Fricke, 2023). As a result, plants under salt stress tend to exhibit lower water loss rates than those in non-saline environments. Further investigation into the mechanisms underlying reduced transpiration under salt stress can provide valuable insights for improving crop resilience and water use efficiency in saline environments.

Also, the EC and TDS values directly correlated with the salt concentrations, with higher salt concentrations resulting in signifcantly higher EC and TDS values. Unexpectedly, *S. portulacastrum* was unable to desalinate the saline water treatments but rather resulted in increased salinity of the saline water. One possible explanation for this outcome could be the increased greenhouse evaporation rate resulting from the exposed water surfaces in the hydroponic pipes. This leads to water loss through evaporation, while the salts remain dissolved and accumulated in the hydroponic system. Additionally, it is possible that *S. portulacastrum* plants, under these stress and hydroponic conditions, employed a

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

salt exclusion mechanism of salt tolerance rather than actively taking up and sequestering the salts into vacuoles or old leaves (Munns, 2005). This mechanism involves preventing salt uptake by roots or minimizing its transport to the shoots, thus avoiding salt accumulation in the plant tissues (Munns, 2005).

The ability of *S. portulacastrum* to maintain relatively lower pH values in the 25 and 50 dS/m salt treatments, compared to the higher pH readings observed in the 0 dS/m treatment, is interesting. This phenomenon could be attributed to the plant's physiological response to salt stress. It is possible that under saline conditions, *S. portulacastrum* plants modify their root exudates or rhizosphere environment, leading to acidification of the surrounding hydroponic solution (McNear, 2013). This acidification process may involve the release of organic acids or other compounds by the roots, which lower the pH and help alleviate the effects of salt stress on the plants (Jones and Darrah, 1994). Moreover, *S. portulacastrum* may also possess mechanisms to regulate pH levels within its tissues or root zone in response to salt stress. These mechanisms could involve ion transporters or channels that facilitate the uptake or exclusion of specific ions, thereby influencing the overall pH of the surrounding environment.

Regarding planting distances, it is notable that higher planting distances consistently maintained higher biomass accumulation across all salt treatments. This observation may be attributed to reduced competition for resources, including water and sunlight, among plants grown at greater distances from each other (Alberio *et al.*, 2015). Also, increased planting distances may mitigate the effects of allelopathy or competition-induced stress, allowing each plant to optimize

Digitized by Sam Jonah Library

resource allocation and minimize resource limitations (Ibrahim and Kandil, 2007; Shan *et al.*, 2023). Spacing plants farther apart reduces negative interactions between neighbouring plants, promoting overall growth and productivity.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the results, the null hypothesis that " There is no significant variation in the types of halophytes found along the Atlantic Ocean coastline in Cape Coast and their respective salt tolerance levels" was rejected. The coastal region of Cape Coast boasts a diverse array of plant species with multifaceted potentials. These plants offer promising opportunities for various purposes, including human and animal nutrition, ecological restoration, and medicinal and therapeutic applications. For instance, edible species like *Ipomoea aquatica* and *Lactuca taraxacifolia* provide nutrients for humans, while species such as *Sesuvium portulacastrum* and *P. vaginatum* contribute to the stabilization of coastal ecosystems, preventing soil erosion and remediating degraded lands. Additionally, medicinal plants like *Capraria biflora* and *Furcarear cabuya* hold traditional healing significance for various illnesses and health conditions. Conservation efforts and interdisciplinary research are essential to unlock the full potential of these botanical resources while ensuring their sustainable use and preservation. *Talinum triangulare*, *I. aquatica*, *L. taraxacifolia*, *S. portulacastrum* and *P. vaginatum*, were selected based on their importance in human and animal nutrition, short lifecycle and simple propagation methods for a greenhouse experiment to study their salt tolerance and remediation abilities.

The null hypothesis that "Salinity does not significantly affect the growth, biomass allocation, or ion accumulation in halophytes grown under controlled

Digitized by Sam Jonah Library

conditions" was rejected. The five (5) selected halophytes were subjected to three salt treatments (0, 25 and 50 dS/m) and two soil types (sea sand and arable soil) to assess their level of salt tolerance and remediation abilities. The arable soil generally resulted in increased growth of the halophytes, revealing the significant role of soil conditions such as soil structure, chemical and nutrient compositions in enhancing plant growth and development. The growth of *Talinum triangulare*, *I. aquatica* and *L. taraxacifolia* were hindered at 25 and 50 dS/m salt treatments, revealing their inability to tolerate and desalinate the soils at these salt concentrations.

On the other hand, *Sesuvium portulacastrum* and *P. vaginatum* demonstrated remarkable phytoremediation capabilities, particularly in mitigating soil salinity and reducing the accumulation of toxic ions such as Na and Cl in the soil. Their effectiveness in reclaiming saline soils, particularly at 25 dS/m salt treatment, highlights their potential for phytoremediation applications, offering sustainable solutions for addressing soil and water salinity issues in affected environments. Among these two halophytes, *S. portulacastrum* showed superior performance by reducing soil salinity and accumulating increased amounts of Na and Cl ions in their tissues at 25 and 50 dS/m salt treatment and was therefore selected for further study of its desalination abilities in a saline hydroponic system on a vertical farm.

The null hypothesis that "Halophytes do not significantly reduce the electrical conductivity (EC), total dissolved solids (TDS), or pH of saline water in hydroponic systems" was partially accepted. Despite its promising

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

phytoremediation capabilities, *S. portulacastrum* exhibited limited desalination capacity in the saline hydroponic system. It rather resulted in an increased electrical conductivity and total dissolved solids of the saline hydroponic water. However, it contributed significantly to the reduction in saline water pH. Further research is needed to explore the mechanisms underlying this pH-reducing effect and its potential applications in water treatment.

6.2 Recommendations

1. It is recommended that the scope of the research be expanded by identifying and studying additional local halophytes with potential desalination capabilities.
2. Conducting molecular studies on the selected halophytes by analyzing the genetic and biochemical pathways involved in salt tolerance is crucial to identifying their salt tolerance mechanisms.
3. Implementing a closed hydroponic system can help reduce water evaporation, contributing to reduced salt concentrations in the hydroponic system.
4. Using smaller gravels, which provide better support and aeration, as a growth medium in the hydroponic system can reduce physical stress on plant roots, thereby contributing to the overall growth of the plants.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

REFERENCES

Abdulrasheed-Adeleke, T., Shaibu, S. O., Agboola, A. R., Hamzah, R. U., & Garba, M. H. (2021). Comparative studies on the effect of processing methods on the nutritional value of Basella alba, Talinum triangulare, Celosia argentea, Amaranthus hybridus and Gnetum africanum leaves. *GSC Advanced Research and Reviews, 6*(3), 044–052.

Abideen, Z., Ansari, R., & Khan, M. A. (2011). Halophytes: potential source of ligno-cellulosic biomass for ethanol production. *Biomass Bioenergy, 35*, 1818–1822. doi:10.1016/j.biombioe.2011.01.023

Abideen, Z., Hameed, A., Koyro, H.-W., Gul, B., Ansari, R., & Khan, M. A. (2014). Sustainable biofuel production from non-food sources-an overview. *Emirates J. Food Agric., 26*(12), 1057–1066. doi:doi: 10.9755/ejfa.v26i12.19107

Acosta-Motos, J. R., Ortuño, M. F., Bernal-Vicente, A., Diaz-Vivancos, P., Sanchez-Blanco, M. J., & Hernandez, J. A. (2017). Plant responses to salt stress: adaptive mechanisms. *Agronomy, 7*(1), 18.

Adebisi, A. A. (2004). Launaea taraxacifolia (Willd.) Amin. In G. J. Grubben, & O. A. Denton, *Plant resources of tropical Africa* (Vol. 2, pp. 362–364). Netherlands: PROTA.

Adejuwon, A., Femi-Akinlosotu, M. O., Omirinde, J. O., Owolabi, O. R., & Afodun, A. M. (2014). Launaea taraxacifolia ameliorates cisplatin-induced hepato-renal injury. *Eur. J. Med. Plants, 4*(5), 528–41. doi:https://doi.org/10.9734/ EJMP/2014/7314

Aderibigbe, O. R., Ezekiel, O. O., Owolade, S., Korese, J. K., Sturm, B., & Hensel, O. (2022). Exploring the potentials of underutilized grain amaranth (Amaranthus spp.) along the value chain for food and nutrition security: A review. Crit. Rev. *Food Sci. Nutr., 62*, 656-669.

Adhikari, N. D., Simko, I., & Mou, B. (2019). Phenomic and Physiological Analysis of Salinity Efefcts on Lettuce. *Sensors, 19*(21), 4814. doi: htts://doi.org/10.3390/s19214814

Adinortey, M. B., Ansah, C., Weremfo, A., Adinortey, C. A., Adukpo, G. E., & Ameyaw, E. O. (2018). DNA damage protecting activity and antioxidant potential of Launaea taraxacifolia leaves extract. *J. Nat. Sci. Biol. Med., 9*(1), 6–13.

Adinortey, M. B., Sarfo, J. K., Quayson, E. T., Weremfo, A., Adinortey, C. A., & Ekloh, W. (2012). Phytochemical screening,proximate and mineral compositin of Launaea taraxacifolia leaves. *Res J Med Plant, 6*(2), 171–9. doi:htts://doi.org/10.3923/rjmp.2012.171.179.

Digitized by Sam Jonah Library

Adu, M. O., Asare, P. A., Yawson, Ackah, F. K., Amoah, K. K., Nyarko, M. A., & Andoh, D. A. (2017). Quantifying variations in rhizosheath and root system phenotypes of landraces and improved varieties of juvenile maize. *Rhizosphere, 3*, 29–39.

Agarie, S., Shimoda, T., Shimizu, Y., Baumann, K., Sunagawa, H., & Kondo, A. (2007). Salt tolerance, salt accumulatin, and ionic homeostasis in an epidermal bladder-cell-less mutant of the common ice plant Mesembryanthemum crystallinum. *J. Exp. Bot., 58*, 1957-1967.

Ahmad, S., Cui, W., Kamran, M., Ahmad, I., Meng, X., Wu, X., . . . Han, Q. (2020). Exogenous Application of Melatonin Induces Tolerance to Salt Stress by Improving the Photosynthetic Effiency and Antioxidant Defense System of Maize Seedling. *Journal of Plant Growth Regulation, 40*, 1270-1283.

Ahmed, S., Ahmed, S., Roy, S. K., Woo, S. H., & Sonawane, K. D. (2019). Effect of salinity on the morphological , physiological and biochemical properties of lettuce (Lactuca sativa L .) in Bangladesh. *Open Agriculture, 4*, 361–373.

Aja, P. M., Okaka, A. N., Onu, P. N., Ibiam, U., & Urako, A. J. (2010). Phytochemical composition of Talinum triangulare (water leaf) leaves. *Pakistan Journal of Nutrition, 9*(6), 527-530.

Akbarimoghaddam, H., Galavi, M., Ghanbari, A., & Panjehkeh, N. (2011). Salinity effects on seed germination and seedling growth of bread wheat cultivars. *Trakia J. Sci., 9*(1), 43–50.

Akhani, H., Barroca, J., Koteeva, N., Voznesenskaya, E., Franceschi, V., Edwards, G., & Ziegler, H. (2005). Bienertia sinuspersici (Chenopodiaceae): a new species from Southwest Asia and discovery of a third terrestrial C4 plant without Kranz anatomy. *Systematic Botany, 30*(2), 290-301.

Akhter, J., Mahmood, K., Malik, K. A., Mardan, A., Ahmad, M., & Iqbal, M. M. (2004). Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. *Plant, Soil Environ., 50*, 463–469. doi:https://doi. org/10.17221/4059-PSE.

Akman, H. (2020). Comparison of Field Crops with Tap and Fibrous Root System at Early and Late Growth Stages. *Turkish Journal of Agriculture-Food Science and Technology*, *8*(5), 1181-1187.

Alam, M. A., Juraimi, A. S., Rafi, M. Y., & Hamid, A. A. (2015). Effect of Salinity on Biomass Yield and Physiological and Stem-Root Anatomical Characteristis of Purslane (Portulaca oleracea L.) Accessions. *BioMed Research Internatinal*, 15. doi:htts://doi.org/10.1155/2015/105695

Digitized by Sam Jonah Library

Albassam, B. A. (2001). Effect of nitrate nutrition on growth and nitrogen assimilation of pearl millet exposed to sodium chloride stress. *Journal of Plant Nutrition,, 24*(9), 1325-1335.

Alberio, C., Izquierdo, N. G., & Aguirrezábal, L. A. N. (2015). Sunflower crop physiology and agronomy. In *Sunflower* (pp. 53-91). AOCS Press.

Albuquerque, U., Medeiros, P., Almeida, A., Monteiro, J., Neto-Lins, E., Melo, J., & Santos, J. (2007). Medicinal plants of the caatiga (semi-arid) vegetatin of NE Brazil: a quantiatie approach. *J. Ethnopharmacol., 114*, 325-354.

Alhaddad, F. A., Abu-Dieyeh, M. H., & El Azazi, E. S. (2021). Salt tolerance of selected halophytes at the two initial growth stages for future management options. *Sci. Rep., 11*, 10194. doi:htts://doi.org/10.1038/s41598-021-89462-3

Almansouri, M., Kinet, J. M., & Lutt, S. (2001). Effect of salt and osmoti stresses on germinatin in durum wheat (Tritium durum Desf.). *Plant Soil, 231*, 243–254. doi: 10.1023/A:1010378409663

Amarasinghe, V., & Watson, L. ,. (1988). Comparatie ultrastructure of microhairs in grasses. *Bot. J. Linn. Soc., 98*, 303-319.

Amirjani, M. R. (2011). Effect of salinity stress on growth, sugar content, pigments and enzyme activity of rice. *International Journal of Botany, 7*(1), 73-81.

Ampofo, E. A. (2006). Soil moisture dynamics in coastal savanna soils in the tropics under different soil management practices. *Hydrological Sciences Journal, 51*(6), 1194-1202. doi:10.1623/hysj.51.6.1194

Andarwulan, N., Faridah, D. N., Prabekti, Y. S., Fadhilatunnur, H., Mualim, L., Aziz, S. A., & Cisneros- Zevallos, L. (2015). Dietary Fiber Content of Waterleaf (Talinum triangulare (Jacq.) Willd) Cultivated with Organic and Conventional Fertilization in Different Seasons. *American Journal of Plant Sciences, 6*, 334-343.

Aparicio, J. D., Raimondo, E. E., Saez, J. M., Costa-Gutierrez, S. B., Alvarez, A., Benimeli, C. S., & Polti, M. A. (2022). The current approach to soil remediation: A review of physicochemical and biological technologies, and the potential of their strategic combination. *Journal of Environmental Chemical Engineering, 10*(2), 107141.

Arámburo-Miranda, I. V., & Ruelas-Ramírez, E. H. (2016). Desalination of sea water with aquatic lily (Eichhornia crassipes). *Environmental Science and Pollution Research, 24*(33), 25676–25681.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Arbelet-Bonnin, D., Hamed-Laouti, I. B., Laurenti, P., Abdelly, C., Ben Hamed, K., & Bouteau, F. (2018). Cellular mechanisms to survive salt in the halophyte Cakile maritia. *Plant Sci., 272*, 173–178.

Arif, M. R., Islam, M. T., & Robin, A. H. (2019). Salinity stress alters root morphology and root hair traits in Brassica napus. *Plants, 8*(7), 192.

Aronson, J. (1989). *HALOPH a Data Base of Salt Tolerant Plants of the World.* Tuscon, Arizona: Office of arid land studies, the University of Arizona, USA.

Asamoah, A., Antwi-Boasiako, C., Frimpong-Mensah, K., & Soma, D. M. (2013). Adoptable Technique(S) for Managing Ghanaian Saline Soils. *Octa Journal of Environmental Research, 1*(1), 48-51.

Asamoah, G. K. (1973). *Soils of the proposed farm site of the University of Cape Coast.* Cape Coast: Soil Research Institute (CSIR) Technical Report.

Asare-Bediako, E., Addo-Quaye, A., & Bi-Kusi, A. (2014). Comparative efficacy of plant extracts in managing whitefly (Bemisia tabaci Gen.) and leaf curl disease in okra (Abelmoschus esculentus L.). *Am. J. Agric. Sci. Technol., 2*(1), 31–41.

Ashraf, M. (2004). Some important physiological selection criteria for salt tolerance in plants. *Flora, 199*, 361–376.

Ashrafuzzaman, M., Khan, M., Shohidullah, S., & Rahman, M. (2000). Effect of Salinity on the Chlorophyll Content, Yield and Yield Components of QPM CV. Nutricta. *Pakistan Journal of Biological Sciences, 3*, 43-46.

Aslam, R., Bostan, N., Nabgha-e-Amen, M. M., & Safdar, W. (2011). A critical review on halophytes: salt tolerant plants. *Journal of Medicinal Plants Research, 5*(33), 7108-7118.

Atta, K., Mondal, S., Gorai, S., Singh, A. P., Kumari, A., Ghosh, T., . . . Jespersen, D. (2023). Impacts of salinity stress on crop plants: improving salt tolerance through geneti and molecular dissection. *Front. Plant Sci., 14*, 1241736. doi:10.3389/fpls.2023.1241736

Ayers, R. S., & Westcot, D. W. (1985). *Water Quality for Agriculture. FAO Irrigation and Drainage Paper no. 29.* Rome: FAO.

Ayyappan, D., Sathiyaraj, G., & Ravindran, K. C. (2016). Phytoextraction of heavy metals by Sesuvium portulacastrum l. a salt marsh halophyte from tannery effluent. *International journal of phytoremediation*, *18*(5), 453–459. https://doi.org/10.1080/15226514.2015.1109606

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Badruzzaman, S. M., & Husain, W. (1992). Some aquatic and marshy land medicinal plants from Hardoi district of Uttar Pradesh. *Fitoterapia, 63*, 245–247.

Balasubramaniam, T., Shen, G., Esmaeili, N., & Zhang, H. (2023). Plants' Response Mechanisms to Salinity Stress. *Plants, 12*, 2253. doi:htts://doi.org/10.3390/plants12122253

Bamidele, J. F., Egharevba, R. K., & Okpoh, I. M. (2007). Physiological changes in seedlings of Talinum triangulare (water leaf) grown in saline conditions. *Asian Journal of Plant Sciences, 6*, 56–60.

Baraniak, J., & Kania-Dobrowolska, M. (2022). The Dual Nature of Amaranth-Functional Food and Potential Medicine. *Foods, 11*(4), 618. doi:https://doi.org/10.3390/foods11040618

Barassi, C. A., Ayrault, G., Creus, C. M., Sueldo, R. J., & Sobero, M. T. (2006). Seed inoculation with Azospirillum mitigates NaCl effects on lettuce. *Sci. Horticulturae, 109*, 8–14.

Barkhadle, A., Ongaro, L., & Pignatti, S. (1994). Pastoralism and plant cover in the lower Shabelle Region, southern Somalia. *Landscape Ecology, 9*(2), 79-88.

Barrett-Lennard, E. G., Malcom, C. V., & Bathgate, A. (2003). *Saltland pastures in Australia-a practical guide* (2 ed.). Canberra, Australia: Land, Water and Wood.

Beard, J. B. (2002). *Turf management for golf courses* (2 ed.). Hoboken, NJ: John Wiley & Sons, Inc.

Bello, S. K., Alayafi, A. H., Al-Solaimani, S. G., & Abo-Elyousr, K. A. (2021). Mitigating soil salinity stress with gypsum and bio-organic amendments: A review. *Agronomy, 11*(9), 1735.

Bergman, M., Varshavsky, L., Gottlieb, H. E., & Grossman, S. (2001). The antioxidant activity of aqueous spinach extract: chemical identification of active fractions. *Phytochemisty, 58*, 143–152.

Bernardino, C. A., Mahler, C. F., Alvarenga, P., Castro, P. M., da Silva, E. F., & Novo, L. A. (2020). Recent advances in phytoremediation of soil contaminated by industrial waste: A road map to a safer environment. In *Bioremediation of industrial waste for environmental safety* (pp. 207–221). Singapore: Springer.

Boraphech, P., Suksabye, P., Kulinfra, N., Kongsang, W., & Thiravetyan, P. (2016). Cleanup of trimethylamine (fishy odor) from contaminated air by various species of Sansevieria spp. and their leaf materials. *International journal of phytoremediation, 18*(10), 1002-1013.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Bose, J., Rodrigo-Moreno, A., & Shabala, S. (2014). ROS homeostasis in halophytes in the context of salinity stress tolerance. *Journal of Experimental Botany, 65*(5), 1241–1257. doi:htts://doi.org/10.1093 /jxb/ert430

Brugnoli, E., & Lauteri, M. (1991). Effects of Salinity on Stomatal Conductance, Photosyntheti Capacity, and Carbon Isotope Discriminatin of Salt-Tolerant (Gossypium hirsutum L.) and Salt-Sensitie (Phaseolus vulgaris L.) C(3) Non-Halophytes. *Plant physiology, 95*(2), 628–635. doi:htts://doi.org/10.1104/pp.95.2.628

Burkill, A. (1966). *Dictionary of the economic products of the Malay Peninsula.* Kuala Lumpur, Malaysia: Ministry of Agriculture and Cooperatives.

Burkill, H. (2004). The Useful Plants of West Tropical Africa. *Royal Botanic Gardens, Kew, 4*, 969.

Burkill, H. M. (1985). The useful plants of West Africa,. *Royal Botanical Gardens, 1*, 11-20.

Burt, C. M., & Isbell, B. (2005). Leaching of accumulated soil salinity under drip irrigatin. *Trans. ASAE*, 2115–2121. doi:10.13031/2013.20097

Candlish, J. K., Gourley, L., & Lee, H. P. (1987). Dietary fiber and starch contents of some Southeast Asian vegetables. *J. Agric. Food Chem., 35*, 319–321.

Casierra-Martíez, H. A., Charris-Olmos, J. C., Caselles-Osorio, A., & Parody-Muñoz, A. (. (2017). Organic Mattr and Nutrients Removal in Tropical Constructed Wetlands Using Cyperus ligularis (Cyperaceae) and Echinocloa colona (Poaceae). *Water, Air, & Soil Pollutin, 228*, 1-10.

Cassel, D. K., & Nielsen, D. R. (1985). Field Capacity and Available Water Capacity. 901-926. doi:10.2136/SSSABOOKSER5.1.2ED.C36

Chahinian, B. J. (2000). Sansevieria masoniana, a new species from the Congo. *Cactus and Succulent Journal, 72*(1).

Chapman, V. J. (1942). The new perspectivein the halophytes. *The Quarterly Review of Biology, 17*, 291-311.

Chen, B. H., Yang, S. H., & Han, I. H. (1991). Characterization of major carotenoids in water convolvulus (Ipomoea aquatica) by open-column, thin-layer and high-performance liquid chromatography. *J. Chromatogr., 543*, 147–155.

Chen, B., Bian, X., Tu, M., Yu, T., Jiang, L., Lu, Y., & Chen, X. (2023). Moderate Salinity Stress Increases the Seedling Biomass in Oilseed Rape (Brassica napus L.). *Plants, 2*(8), 1650. doi:htts://doi.org/10.3390/plants12081650

Digitized by Sam Jonah Library

Chen, M., Yang, Z., Liu, J., Zhu, T., Wei, X., Fan, H., & Wang, B. (2018). Adaptatin Mechanism of Salt Excluders under Saline Conditins and Its Applicatins. *Internatinal Journal of Molecular Sciences, 19*(11), 3668. doi: htts://doi.org/10.3390/ijms19113668

Chinedum, O. E., & Kate, C. (. (2013). Bioactive Constituents and In vitro Antioxidant Capacity of Water Leaf (Talinum triangulare) as Affected by Domestic Cooking. *European Journal of Medicinal Plants, 3*, 540-551.

Choukr-Allah, R. (1997). The Potential of Salt-Tolerant Plants for Utilization of Saline Water. *Options Mediterraneennes. Serie A : Seminaires Mediterraneens (CIHEAM)* (pp. 313-325). Marrakech (Morocco): CIHEAM-IAMB.

Christiansen, A. H., Lyra, D. A., & Jørgensen, H. (2021). Increasing the value of Salicornia bigelovii green biomass grown in a desert environment through biorefining. *Industrial Crops and Products, 160*, 113105.

Ciriminna, R., Chavarría-Hernández, N., Rodríguez-Hernández, A., & Pagliaro, M. (2019). Toward unfolding the bioeconomy of nopal (Opunti spp.). *Biofuels*, 13.

Cuevas, J., Daliakopoulos, I. N., del Moral, F., Hueso, J. J., & Tsanis, I. K. (2019). A Review of Soil-Improving Cropping Systems for Soil Salinization. *Agronomy, 9*, 295. doi:10.3390/agronomy9060295

Dadkhah, A. R., & Grrifiths, H. (2006). The effect of salinity on growth, inorganic ions and dry matter partiining in sugar beet cultiars. *Journal of Agricultural Science and Technology, 8*, 199–210.

Darko, H. F., Karikari, A. Y., Duah, A. A., Akurugu, B. A., Mante, V., & Teye, F. O. (2021). Effect of small-scale illegal mining on surface water and sediment quality in Ghana. *International Journal of River Basin Management*. doi:10.1080/15715124.2021.2002345

Dassanayake, M., & Larkin, M. D. (2017). Making plants break a sweat: the structure, function, and evolution of plant salt glands. *Front. Plant Sci., 8*, 406.

Daunay, M., Laterrot, H., & Janick, J. (2007). Iconography of the solanaceae from antiquity to the xviith century: a rich source of information on genetic diversity and uses.

De Freitas, P. A., de Souza Miranda, R., Marques, E. C., Prisco, J. T., & Gomes-Filho, E. (2018). Salt Tolerance Induced by Exogenous Proline in Maize Is Related to Low Oxidatie Damage and Favorable Ionic Homeostasis. *J. Plant Growth Regul., 37*, 911–924. doi:10.1007/s00344-018-9787-x

Digitized by Sam Jonah Library

De Pascale, S., Ruggiero, C., Barbieri, G., & Maggio, A. (2003). Physiological responses of pepper to salinity and drought. *Journal of the American Society for Horticultural Science, 128*(1), 48-54.

Dhanasekaran, S., & Muralidaran, P. (2010). CNS depressant and antiepileptic 55 activities of the methanol extract of the leaves of Ipomoea aquatica Forsk. *E. J. Chem., 7*, 15–61.

Díaz, M. D., Rosa, P. B., Héliès-Toussaint, C., Guéraud, F., & Nègre-Salvayre, A. (2017). Opunti spp.: Characterizatin and Benefis in Chronic Diseases. *Oxidative Medicine and Cellular Longevity*, 17.

Doe (1994) Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea water. Version 2, Dickson, A.G. and Goyet, C., Eds., ORNL/CDIAC-74, Oak Ridge, Tennessee.

Dolatabadian, A., Sanavy, S. A., & Ghanati, F. (2011). Effect of salinity on growth, xylem structure and anatomical characteristics of soybean. *Notulae Scientia Biologicae*, 41-45.

Duke, J. (2008). Duke's Handbook of Medicinal Plants of Lati America (1st ed.). *CRC Press.*

Duke, J. A., & Ayensu, E. S. (1985). *Medicinal plants of China.* Algonac Michigan: Reference Publications.

Edie, H. H., & Ho, W. C. (1969). Ipomoea aquatica as a vegetable crop in Hong Kong. *Econ. Bot., 23*(1), 32–36.

El Moukhtari, A., Cabassa-Hourton, C., M, F., & A, S. (2020). How Does Proline Treatment Promote Salt Stress Tolerance During Crop Plant Development? *Front. Plant Sci., 11*, 1127. doi:10.3389/fpls.2020.01127

Fabbri, L., Perreta, M., & Rua, G. (2016). Spatil structure and development of Paspalum vaginatum (Poaceae): an architectural approach. *Australian Journal of Botany, 64*, 153-159.

Fahad, S., & Wang, J. (2018). Farmers' risk perception, vulnerability, and adaptation to climate change in rural Pakistan. *Land Use Policy, 79*, 301-309. Retrieved from https://www.sciencedirect.com/science/article/pii/S0264837718306227

Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., & Zohaib, A. (2017). Crop production under drought and heat stress: plant responses and management options. *Plant Sci. Fron., 1147*. doi:10.3389/fpls.2017.01147

FAO. (2000). *Global Network on Integrated Soil Management for Sustainable Use of Salt Affected Soils.* FAO. Retrieved from http://www.fao.org/ag/agl/country=ghana

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Feng, Z. T., Sun, Q. J., Deng, Y. Q., Sun, S. F., Zhang, J. G., & Wang, B. S. (2014). Study on pathway and characteristis of ion secretin of salt glands of Limonium bicolor. *Acta. Physiol. Plant, 36*, 2729-2741.

Flowers, T. (1985). Physiology of halophytes. *Plant Soil., 89*(1-3), 41–56. doi:10.1007/BF02182232.

Flowers, T. J., & Colmer, T. D. (2008). Salinity tolerance in halophytes. *New Phytologist, 179*, 945-963. doi: https://doi.org/10.1111/j.1469-8137.2008.02531.x

Flowers, T. J., & Colmer, T. D. (2015). Plant salt tolerance: adaptations in halophytes. *Annals of botany, 115*(3), 327–331. doi:https://doi.org/10.1093/aob/mcu267

Flowers, T. J., Galal, H. K., & Bromham, L. (2010). Evolution of halophytes: multiple origins of salt tolerance in land plants. *Functional Plant Biology*, *37*(7), 604-612.

Fontalvo, E., Paz, N., Gutirrez, E., Caldera, Y., & Núñez, M. (2011). Use of subsurface flw constructed wetlands for the removal of copper and lead from oil productin water. *Revista Tecnica De La Facultad De Ingenieria Universidad Del Zulia*, 34.

Fontem, D. A., & Schippers, R. R. (2004). Talinum triangulare (Jacq.) Willd. [Internet] Record from Protabase. In G. J. Grubben, & O. A. Denton, *PROTA (Plant Resources of Tropical Africa/Ressources ve´ge´tales de l'Afrique tropicale).* Wageningen, Netherlands. doi:http://database.prota.org/search.htm

Fontenot, D. (2007). *Evaluating seashore paspalum seed germination and enhancement, erosion abatement and potential use as a vegetative landform cap.* Louisiana: Master of Science Thesis, Louisiana State University.

Forkutsa, I., Sommer, R., Shirokova, Y. I., Lamers, J. P., Kienzler, K., & Tischbein, B. (2009). Modeling Irrigated Cotton with Shallow Groundwater in the Aral Sea Basin of Uzbekistan: II. Soil Salinity Dynamics. *Irrigation Science, 27*, 319–330. doi:10.1007/s00271-009-0149-0

Fosu, M., Kuhne, R. F., & Vlek, P. (2004). Improving Yield in the Guinea Savannah Zone with Leguminous Cover Crops and KP Fertilization. *Journal of Agronomy, 3*(2), 115-121.

Fru, B. S., Francis, N. A., Angwafo, T. E., & Precillia, T. N. (2017). Waterleaf (Talinum triangulare) response to biochar application in a humid-tropical forest soil. *Journal of Soil Science and Environmental Management, 8*, 95-103.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Gama, P. B., Inanaga, S., Tanaka, K., & Nakazawa, R. (2007). Physiological response of common bean (Phaseolus vulgaris L.) seedlings to salinity stress. *African Journal of Biotechnology, 6*(2), 079 –088.

Gamble, J. S. (1921). *Flora of the presidency of Madras.* India: Digital Library of India.

Garg, B. K., Burman, U., & Kathju, S. (2006). Alleviation of salinity effects by nitrogen fertilization on photosynthesis, nitrogen metabolism and yield of Indian mustard. *Indian Journal of Plant Physiology, 11*(2), 145-151.

Gaudin, S. Identification of forest tree species with a mobile phone: dream or reality? A test of Pl@ ntNet app. 74(3), 359-372.

Ghassemi-Golezani, K., Hosseinzadeh-Mahootchi, A., & Farhangi-Abriz, S. (2020). Chlorophyll a florescence of saffler affected by salt stress and hormonal treatments. , 2. *SN Applied Sciences, 2*.

Ghnaya, T., Nouairi, I., Slama, I., Messedi, D., Grignon, C., Abdelly, C., & Ghorbel, M. H. (2005). Cadmium effects on growth and mineral nutrition of two halophytes: Sesuvium portulacastrum and Mesembryanthemum crystallinum. *J. Plant Physiol., 162*(10), 1133– 1140. doi:10.1016/j.jplph.2004.11.011

Ghnaya, T., Slama, I., Messedi, D., Grignon, C., Ghorbel, M. H., & Abdelly, C. (2007a). Effect of Cd2+ on K+,Ca+ and N uptake in two halo- phytes Sesuvium portulacastrum and Mesembrynathemum crystallinum: consequences on growth. *Chemosphere, 67*, 72–79. doi:10.1016/j.chemosphere.2006.09.064

Ghnaya, T., Slama, I., Messedi, D., Grignon, C., Ghorbel, M. H., & Abdelly, C. (2007b). Cd-induced growth reduction in the halophyte Sesuvium portulacastrum is significantly improved by NaCl. *J. Plant Res., 120*, 309–316. doi:10.1007/s10265-006-0042-3

Giorio, P., & Sellami, M. H. (2021). Polyphasic OKJIP Chlorophyll a Fluorescence Transient in a Landrace and a Commercial Cultivar of Sweet Pepper (Capsicum annuum, L.) under Long-Term Salt Stress. *Plants, 10*(5), 887. doi:10.3390/plants10050887

Glenn, E., Brown, J., & Blumwald, E. (1999). Salt Tolerance and Crop Potential of Halophytes. *Crit. Rev. Plant Sci., 18*, 227–255.

Godfray, H., Beddington, J., Crute, I., Haddad, L., Lawrence, D., Muir, J., . . . Toulmin, C. (2010). Food security: the challenge of feeding 9 billion people. *Science, 327*, 812–818.

Digitized by Sam Jonah Library

Goëau, H., Bonnet, P., Joly, A., Affouard, A., Bakic, V., Barbe, J., ... & Boujemaa, N. (2014, April). Pl@ ntnet mobile 2014: Android port and new features. In Proceedings of international conference on multimedia retrieval (pp. 527-528).

Graifenberg, A., Botrini, L., Giustiniani, L., Filippi, F., & Curadi, M. (2003). Tomato growing in saline conditions with biodesalinating plants: Salsola soda L. and Portulaca oleracea L. *Acta Hort., 609*, 301–305.

Greenway, H. G. (1966). Plant Response to Saline Substrates VIII. Regulation of Ion Concentrations in Salt-Sensitive and Halophytic Species. *Australian Journal of Biological Sciences, 19*, 741 -756.

Grigore, M. N. (2021). Definition and classification of halophytes as an ecological group of plants. In *Handbook of halophytes: from molecules to ecosystems towards biosaline agriculture* (pp. 3-50). Cham: Springer International Publishing.

Grover, M., Ali, S. Z., Sandhya, V., Rasul, A., & Venkateswarlu, B. (2011). Role of microorganisms in adaptatin of agriculture crops to abioti stresses. *World J. Microbiol. Biotechnol., 27*, 1231–1240.

Guo, H., Tao, C., & Huang, Z. (2020). Metamorphic Testing for Plant Identifiation Mobile Applications. In *International Conference on Mobile Computing, Applications, and Services* (pp. 209-223). Cham: Springer International Publishing.

Guo, Z., Wei, M. Y., Zhong, Y. H., Wu, X., Chi, B. J., Li, J., & Zheng, H. L. (2023). Leaf sodium homeostasis controlled by salt gland is associated with salt tolerance in mangrove plant Avicennia marina. *Tree Physiology, 43*(5), 817-831.

Gururani, M., Venkatesh, J., & Tran, L. S. (2015). Regulatin of photosynthesis during abiotic stress-induced photoinhibition. *Mol. Plant, 8*, 1304–1320.

Hamdani, F., Derridj, A., & Rogers, H. J. (2017). Multile mechanisms mediate growth and survival in young seedlings of two populatins of the halophyte Atriplex halimus (L.) subjected to long single-step salinity treatments. *Funct. Plant Biol., 44*, 761–773.

Hameed, A., Ahmed, M. Z., Hussain, T., Aziz, I., Ahmad, N., Gul, B., & Nielsen, B. L. (2021). Effects of Salinity Stress on Chloroplast Structure and Function. *Cells, 10*(8), 2023. doi:htts://doi.org/10.3390/cells10082023

Hand, M. J., Taffouo, V. D., Nouck, A. E., Nyemene, K. P., Tonfack, B., Meguekam, T. L., & Youmbi, E. (2017). Effects of Salt Stress on Plant Growth, Nutrient Partitioning, Chlorophyll Content, Leaf Relative Water Content, Accumulation of Osmolytes and Antioxidant Compounds in Pepper

Digitized by Sam Jonah Library

(Capsicum annuum L.) Cultiars. *Notulae Botanicae Hort Agrobotanici Cluj-Napoca, 45*(2), 481–490. doi:htts://doi.org/10.15835/nbha45210928

Hasanuzzaman, M., Fujita, M., Islam, M. N., Ahamed, K. U., & Nahar, K. (2009). Performance of four irrigated rice varieties under different levels of salinity stress. *International Journal of Integrative Biology, 6*(2), 85-90.

Hasanuzzaman, M., Nahar, K., & Fujita, M. (2013). Plant response to salt stress and role of exogenous protectants to mitigate salt-induced damages. *Ecophysiology and responses of plants under salt stress*, 25-87.

He, W., Wang, D., Yang, N., Cao, D., Chen, X., Chen, J., & X., W. (2022). In Vitro Shoot Culture of Sesuvium portulacastrum: An Important Plant for Phytoremediatin. *Agriculture, 12*(1), 47.

Heidari, M. (2012). Effects of salinity stress on growth, chlorophyll content and osmotic components of two basil (Ocimum basilicum L.) genotypes. *African Journal of Biotechnology, 11*(2), 379-384.

Hermans, C., Hammond, J. P., White, P. J., & Verbruggen, N. (2006). How do plants respond to nutrient shortage by biomass allocation? *Trends in plant science*, *11*(12), 610-617.

Heuzé, V., Tran, G., Maxin, G., & Lebas, F. (2016, April 19). *Creeping indigo (Indigofera spicata and Indigofera hendecaphylla)*. Retrieved from Feedipedia – Animal Feed Resources Informatin System. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO.

Hmidi, D., Abdelly, C., Athar, H. U., Ashraf, M., & Messedi, D. (2018). Effect of salinity on osmotic adjustment, proline accumulatin and possible role of ornithine-δ-aminotransferase in proline biosynthesis in Cakile maritia. *Physiology and Molecular Biology of Plants, 24*(6), 1017–1033. doi:htts://doi.org/10.1007/s12298-018-0601-9

Hnilickova, H., Kraus, K., Vachova, P., & Hnilicka, F. (2021). Salinity Stress Affects Photosynthesis, Malondialdehyde Formation, and Proline Content in Portulaca oleracea L. *Plants, 10*(5), 845. doi:htts://doi.org/10.3390/plants10050845

Hoffmann, J., Berni, R., Sutera, F. M., Gutsch, A., Hausman, J. F., Saffie-Siebert, S., & Guerriero, G. (2021). The effects of salinity on the anatomy and gene expression patterns in leaflets of tomato cv. micro-tom. *Genes, 12*(8), 1165.

Hoque, M. N., Chakrobortt, J., Sarker, P., Irin, I. J., Bresti, M., & Rhaman, M. S. (2022). Organic Amendments for Mitiatin of Salinity Stress in Plants: A Review. *Life (Basel, Switzerland), 12*(10), 1632. doi:htts://doi.org/10.3390/life12101632

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Hsouna B. A., Ghneim-Herrera, T., Ben, R. W., Dabbous, A., Ben Saad, R., Brini, F., . Ben Hamed, K. (2020). Early effects of salt stress on the physiological and oxidatie status of the halophyte *Lobularia maritima*. *Funct. Plant Biol., 47*, 912–924.

Hu, Y., & Schmidhalter, U. (2002). Limitation of salt stress to plant growth. In B. Hock, & C. Elstner, *Plant Toxicology* (pp. 91–224). New York: Marcel Dekker Inc.

Huang, J., Liu, N., Ren, H., & Jian, S. G. (2019). Physiology and biochemical characteristics of Canavalia rosea under stress. *J. Trop. & Subtrop. Bot., 27*(2), 157–163.

Hue, N. V., Campbell, S., Li, Q. X., Lee, C. R., & Fong, J. (2002). Reducing salinity and organic contaminants in the Pearl Harbor dredged material using soil amendments and plants. *Remediation Journal*, *12*(4), 45-63.

Hulkko, L. S., Turcios, A. E., Kohnen, S., Chaturvedi, T., Papenbrock, J., & Thomsen, M. H. (2022). Cultivation and characterisation of Salicornia europaea, Tripolium pannonicum and Crithmum maritimum biomass for green biorefinery applications. *Scientific reports, 12*(1), 20507. doi:https://doi.org/10.1038/s41598-022-24865-4

Husain, S., Von Caemmerer, S., & Munns, R. (2004). Control of salt transport from roots to shoots of wheat in saline soil. *Funct. Plant Biol., 31*, 1115–1126. doi: 10.1071/FP04078

Hussein, M. M., El-Faham, S. Y., & Alva, A. K. (2012). Pepper plants growth, yield, photosynthetic pigments, and total phenols as affected by foliar application of potassium under different salinity irrigation water. *Agricultural Sciences, 3*(2), 241-248. doi:10.4236/as.2012.32028

Ibrahim, M. H., Abas, N. A., & Zahra, S. M. (2019). Impact of salinity stress on germination of water spinach (Ipomoea aquatica). *Annual Research & Review in Biology, 31*(5), 1-12.

Ibrahim, S. A., & Kandil, H. (2007). Growth, yield and chemical constituents of soybean (Glycin max L.) plants as affect by plant spacing under different irrigation intervals. *Research Journal of Agriculture and Biological Sciences*, *3*(6), 657-663.

ICAR–Central Soil Salinity Research Institute. (2015). Vision 2050. *Indian Council of Agricultural Research*, 31.

Igwenyi, I. O., Offor, C. E., & Ajah, D. A. (2011). Chemical compositions of Ipomoea aquatica (green kangkong). *Int. J. Pharm. Bio. Sci., 2*(4), 593–598.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Internation Energy Agency. (2007). Bioenergy 28th Update. *Biomass Bioenergy, 31*, I–XI.

Islam, M. S., Hosen, M. M., & Uddin, M. N. (2019). Phytodesalination of saline water using Ipomoea aquatica, Alternanthera philoxeroides and Ludwigia adscendens. *International Journal of Environmental Science and Technology,, 16*, 965-972. doi:https://doi.org/10.1007/s13762-018-1705-z

Ivushkin, K., Bartholomeus, H., Bregt, A. K., Pulatov, A., Kempen, B., & de Sousa, L. (2019). Global Mapping of Soil Salinity Change. *Remote Sensing Environ., 231*, 111260. doi:doi:10.1016/j.rse.2019.111260

Jakhar, S., Bhupnesh, & Goyal, V. (2024). Promoting Sustainable Agriculture: Approaches for Mitigating Soil Salinity Challenges: A Review. *Agricultural Reviews*. doi:10.18805/ag.R-2648

Jaleel, C. A., Sankar, B., Sridharan, R., & Panneerselvam, R. (2008). Soil Salinity Alters Growth, Chlorophyll Content, and Secondary Metabolite Accumulation in Catharanthus roseus. *Turkish Journal of Biology, 32*(2). doi:htts://journals.tubitak.gov.tr/biology/vol32/iss2/2

Jamil, M., Rehman, S., & Rha, E. S. (2007). Salinity effect on plant growth, PSII photochemistry and chlorophyll content in sugar beet (Beta vulgaris L.) and cabbage (Brassica oleracea capitata L.). *Pak. J. Bot,, 39*(3), 753-760.

Jefferies, R. L., Davy, A. J., & Rudmik, T. (1979). 15. THE GROWTH STRATEGIES OF COASTAL HALOPHYTES.

Jimoh, M. O., Okaiyeto, K., Oguntibeju, O. O., & Laubscher, C. P. (2022). A systematic review on Amaranthus-related research. *Horticulturae*, *8*(3), 239.

Joly, A., Goëau, H., Bonnet, P., Bakić, V., Barbe, J., Selmi, S., . . . Barthélémy, D. (2014). Interactive plant identification based on social image data. *Ecological Informatics, 23*, 22-34. doi:https://doi.org/10.1016/j.ecoinf.2013.07.006

Jones, D. L., & Darrah, P. R. (1994). Role of root derived organic acids in the mobilization of nutrients from the rhizosphere. *Plant and soil*, *166*, 247-257.

Joshi, G. V., & Bhosale, L. J. (1981). Estuarine ecosystem ofIndia. In D. N. Sen, & K. S. Tajpurohit, *Contributions to the ecology of halophytes* (pp. 21–33). The Hague: Dr. W. Junk Publications.

Joshi, R., Dkhar, J., Singla-Pareek, S. L., & Pareek, A. (2019). Molecular mechanism and signaling response of heavy metal stress tolerance in plants. In *Plant-metal interactions* (pp. 29–47). Cham: Springer.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Joshi, R., Pilcher, W., Ramanarao, M., Bedre, R., Sanchez, L., Zandkarimi, H., & N., B. (2015). Salt Adaptation Mechanisms of Halophytes: Improvement of Salt Tolerance in Crop Plants. In G. Pandey, *Elucidation of Abiotic Stress Signaling in Plants* (pp. 243–279). New York: Springer. Retrieved from https://doi.org/10.1007/978-1-4939-2540-7_9

Jumberi, A., Oka, M., & Fujiyama, H. (2002). Response of vegetable crops to salinity and sodicity in relation to ionic balance and ability to absorb microelentents. *Soil Science and Plant Nutrition, 48*(2), 203-209.

Karaca, C., Aslan, G. E., Buyuktas, D., Kurunc, A., Bastug, R., & Navarro, A. (2022). Effects of Salinity Stress on Drip-Irrigated Tomatoes Grown under Mediterranean-Type Greenhouse Conditions. *Agronomy, 13*(1), 36.

Karagiannis, P., & Soldatos, I. (2008). Water desalination cost literature: Review and assessment. *Desalination, 223*(1-3), 448-456.

Karimi, I. Y., Kurup, S. S., Salem, M. A., Cheruth, A. J., Purayil, F. T., & Subramaniam, S. (2018). Evaluation ofbermuda and paspalum grass types for urban landscapes under saline water irrigation. *J. Plant Nutr., 41*, 888–902. doi:10.1080/01904167.2018.1431669

Katsoulas, N., & Stanghellini, C. (2019). Modelling crop transpiration in greenhouses: Different models for different applications. *Agronomy*, *9*(7), 392.

Kefu, Z., & Hai, F. (2000). Comparative study on osmotica and their contributions to osmotic adjustment in eu-halophytes and recretohalophytes. *Chinese Journal of Appplied Environmental Biology, 6*, 99-105.

Kemp, P. R., & Cunningham, G. L. (1981). Light, Temperature and Salinity Effcts on Growth, Leaf Anatomy and Photosyntesis of Distihlis spicata (L.) Greene. *American Journal of Botany, 68*(4), 507–516. doi: 10.2307/2443026

Khan, A. A., Rao, S. A., & McNeilly, T. (2003). Assessment of salinity tolerance based upon seedling root growth response functions in maize (Zea mays L.). *Euphytica, 131*, 81-89.

Khan, M. A., & Ungar, I. (1998). Germination of salt tolerant shrub Suaeda frutiosa from Pakistan: Salinity and temperature responses. *Seed Sci. Technol., 26*, 657-667.

Khan, M. J., Jan, M. T., Khan, A. U., Arif, M., & Shafi, M. (2010). Management of Saline Sodic Soils Through Cultural Practices and Gypsum. *Pak. J. Bot., 42*(6), 4143-4155.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Khan, M., Ungar, I., & Showalter, A. (2000). Growth, water, and ion relationships of a leaf succulent perennial halophyte, Suaeda frutiosa (L.) Forssk. *J. Arid Environ., 45*, 73-84.

Khare, C. P. (2007). *Indian medicinal plants: an illustrated dictionary.* New York: Springer.

Koukoui, O., Agbangnan, P., Boucherie, S., Yovo, M., Nusse, O., & Combettes, L. (2015). Phytochemical study and evaluation of cytotoxicity, antioxidant and hypolipidaemic properties of Launaea taraxacifolia leaves extracts on cell lines HepG 2 and PLB 985. *Am. J. Plant Sci., 6*(11), 1768–79. doi:https://doi. org/10.4236/ajps.2015.611177

Kranner, I., Minibayeva, F. V., Becket, R. P., & Seal, C. E. (2010). What is stress? Concepts, definitions and applicatins in seed science. *New Phytol., 188*, 655–673. doi:10.1111/j.1469-8137.2010.03461.x

Ksouri, R., Ksouri, W. M., Jallali, I., Debez, A., Magné, C., Hiroko, I., & Abdelly, C. (2012). Medicinal halophytes: potent source of health promoting biomolecules with medical, nutraceutical and food applications. *Critical reviews in biotechnology*, *32*(4), 289–326. https://doi.org/10.3109/07388551.2011.630647

Kumar, S., Li, G., Yang, J., Huang, X., Ji, Q., Liu, Z., . . . Hou, H. (2021). Effect of Salt Stress on Growth, Physiological Parameters, and Ionic Concentratin of Water Dropwort (Oenanthe javanica) Cultiars. *Front. Plant Sci., 12*(660409). doi:10.3389/fpls.2021.660409

Kumari, A., & Parida, A. (2018). Metabolomics and network analysis reveal the potentil metabolites and biological pathways involved in salinity tolerance of the halophyte Salvadora persica. *Environ. Exp. Bot., 148*, 85–99.

Kumawat, C., Kumar, A., Parshad, J., Sharma, S. S., Patra, A., Dogra, P., . . . Kumawat, G. L. (2022). Microbial Diversity and Adaptatin under Salt-Affcted Soils: A Review. *Sustainability, 14*(15), 9280. doi:htts://doi.org/10.3390/su14159280

Kumi, F., Obour, P. B., Arthur, E., Moore, S. E., Asare, P. A., Asiedu, J. & Adu, M. O. (2023). Quantifying root-induced soil strength, measured as soil penetration resistance, from different crop plants and soil types. *Soil and Tillage Research, 233*, 105811. Retrieved from https://www.sciencedirect.com/science/article/pii/S0167198723001782

Kushiev, H., Noble, A., Abdullaev, I., & Toshbekov, U. (2005). Remediation of abandoned saline soils using glycyrrhiza glabra: a study from the hungry steppes of Central Asia. *Int. J. Agric. Sustain., 3*(2), 102–113.

Digitized by Sam Jonah Library

Kushwaha, A., Rani, R., Kumar, S., & Gautam, A. (2015). Heavy metal detoxification and tolerance mechanisms in plants: Implications for phytoremediation. *Environmental Reviews, 24*(1).

Lal, R. (2004). Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science, 304*, 1623-1627. Retrieved from https://doi.org/10.1126/science.1097396

Larcher, W. (2003). *Physiological plant ecology: ecophysiology and stress physiology of functional groups* (4 ed.). Berlin: Springer Science & Business Media.

Le Houérou, H. N. (1979). Resources and Potential of the Native Flora for Fodder and Sown Pastures Production in the Arid and Semi-Arid Zones of North Afiica. In J. Goodin, & D. Northington, *Arid Land Plant Resources* (pp. 384-400). Lubbock, TX: ICASALS, Texas Tech. Univ.,.

Le Houérou, H. N. (1985). Salt-Tolerant Plants of Economic Value in the Mediterranean Basin. *Reclamation and Revegetation Research*.

Le Houérou, H. N. (1986). Salt Tolerant Plant of Economic value in the Mediterranean Basin. *Reclamation and Revegetation Research, 5*, 319-341.

Levitt, J. (1980). *Responses of Plant to Environmental Stress Chilling, Freezing, and High Temperature Stresses* (2 ed.). NewYork: Academic Press.

Li, N., Zhou, X., Wang, R., Li, J., Lu, C., & Chen, S. (2018). Salt Compartmentation and Antixidant Defense in Roots and Leaves of Two Non-Salt Secretor Mangroves under Salt Stress. *InTech*. doi:10.5772/intechopen.75583

Li, S., Li, C., & Fu, X. (2021). Characteristics of soil salt crust formed by mixing calcium chloride with sodium sulfate and the possibility of inhibitig wind-sand flow. *Sci. Rep., 11*, 9746.

Lin, R., Zheng, J., Pu, L., Wang, Z., Mei, Q., Zhang, M., & Jian, S. (2021). Lin, R., Zheng, J., Pu, L., Wang, Z., Mei, Q., Zhang, M., & Jian, S. (2021). Genome-wide identification and expression analysis of aquaporin family in Canavalia rosea and their roles in the adaptation to saline-alkaline soils and drought stress. *BMC plant biology, 21*(1), 333.

Litalien, A., & Zeeb, B. (2020). Curing the Earth: A Review of Anthropogenic Soil Salinization and Plant-Based Strategies for Sustainable Mitigation. *Sci. Total Environ. , 698*, 134235. doi: doi:10.1016/j.scitotenv.2019.134235

Liu, Y., Zhang, S., De-Boeck, H. J., & Hou, F. (2021). Effects of Temperature and Salinity on Seed Germinatin of Three Common Grass Species. *Front. Plant Sci., 12*, 731433. doi:10.3389/fpls.2021.731433

Digitized by Sam Jonah Library

Lokhande, V. H., Gor, B. K., Desai, N. S., Nikam, T., & Suprasanna, P. (2013). Sesuvium portulacastrum, a plant for drought, salt stress, sand fixation, food and phytoremediatin. A review. *Agron. Sustain. Dev., 33*, 329–348.

Lokhande, V. H., Nikam, T. D., & Suprasanna, P. (2010a). Biochemical, physiological and growth changes in response to salinity in callus cultures of Sesuvium portulacastrum L. *Plant Cell Tiss. Org. Cult., 102*, 17–25. doi:10.1007/s11240-010-9699-3

Lokhande, V. H., Nikam, T. D., & Suprasanna, P. (2010b). Differential osmotic adjustment to iso-osmotic salt and PEG stress in vitro in the halophyte Sesuvium portulacastrum L. *J. Crop Sci. Biotechnol., 13*(4), 251–256. doi:10.1007/s12892-010-0008-9

Lokhande, V. H., Nikam, T. D., Patade, V. Y., & Suprasanna. (2009). Morphological and molecular diversity analysis among the Indian clones ofSesuvium portulacastrum L. *Genet. Res. Crop Evol., 56*, 705–717. doi:10.1007/s10722-008-9396-9

Lokhande, V. H., Nikam, T. D., Patade, V. Y., Ahire, M. L., & Suprasanna, P. (2011a). Effects of optimal and supra-optimal salinity stress on antioxidative defense, osmolytes and in vitro growth responses in Sesuvium portulacastrum L. *Plant Cell Tiss. Org. Cult, 104*, 41–49.

Lokhande, V. H., Srivastava, A. K., Srivastava, S., Nikam, T. D., & Suprasanna, P. (2011c). Regulated alterations in redox and energetic status are the key mediators of salinity tolerance in the halophyte Sesuvium portulacastrum (L.) L. *Plant Grow Regul., 65*(2), 287–298. doi:10.1007/s10725-011-9600-3

Lokhande, V. H., Srivastava, S., Patade, V. Y., Dwivedi, S., Tripathi, R. D., Nikam, T. D., & Suprasanna, P. (2011b). Investigation of arsenic accumulation and tolerance in Sesuvium portulacastrum (L.) L. *Chemosphere, 82*(4), 529–534. doi:10.1016/j.chemosphere.2010.10.05

Lonard, R. I., & Judd, F. W. (1997). The biological flora of coastal dunes and wetlands. Sesuvium portulacastrum (L.) L. *J. Coast. Res., 13*(1), 96– 104.

Lu, Y., & Fricke, W. (2023). Salt Stress-Regulation of Root Water Uptake in a Whole-Plant and Diurnal Context. *International journal of molecular sciences*, *24*(9), 8070. https://doi.org/10.3390/ijms24098070

Lutts, S., Kinet, J. M., & Bouharmont, J. (1996). NaCl-induced Senescence in Leaves of Rice (Oryza sativa L.) Cultivars Differing in Salinity Resistance. *Annals of Botany, 78*(3), 389–398. doi:https://doi.org/10.1006/anbo.1996.0134

Digitized by Sam Jonah Library

Lv, S., Jiang, P., Tai, F., Wang, D., Feng, J., Fan, P. & Li, Y. (2017). The V-ATPase subunit A is essential for salt tolerance through participating in vacuolar Na+ compartmentalization in Salicornia europaea. *Planta, 246*(6), 1177–1187. doi: https://doi.org/10.1007/s00425-017-2762-0

Maggio, A., Raimondi, G., Martio, S., & De Pascale, S. .. (2007). Salt stress response in tomato beyond the salinity tolerance threshold. *Environmental and Experimental Botany, 59*, 276 – 282.

Malakar, C., Talukdar, A., & Choudhury, P. (2015). Pharmacological Potentiality and Medicinal Uses of Ipomoea Aquatica Forsk: A Review. *Asian Journal of Pharmaceutical and Clinical Research, 8*, 60-63.

Malcolm, C., & Pol., J. (1986). Grazing and management of saltl and shrubs. *Journal of Agriculture Western Australia, 27*, 59-63.

Mane, A. V., Saratale, G. D., Karadge, B. A., & Samant, J. S. (2011). Studies on the effects of salinity on growth, polyphenol content and photosynthetic response in Vetieria zizanioides (L.) Nash. *Emirates Journal of Food and Agriculture, 23*(1), 59–70.

Mann, A., Kumar, N., Kumar, A., Lata, C., Kumar, A., Meena, B., . . . Parameswaran, C. (2021). De novo transcriptomic profiing of diffrentilly expressed genes in grass halophyte Urochondra setulosa under high salinity. *Sci. Rep., 11*, 1–14.

Mann, A., Kumar, N., Lata, C., Kumar, A., & Kumar, A. (2018). Halophytes-Miracle Plants to Survive in Extreme Saline Environment. *Open Access Journal of Agricultural Research, 3*(5), 1-4.

Manousaki, E., & Kalogerakis, N. (2011). Halophytes – An emerging trend in phytoremediation. *International Journal of Phytoremediation, 13*(10), 959–969.

Marcum, K. B., & Murdoch, C. L. (1994). Salinity tolerance mechanisms of six C4 turfgrasses. *J. Am. Soc. Hortic. Sci., 119*, 779–784. doi:10.21273/JASHS. 119.4.779

Marriboina, S., Sengupta, D., Kumar, S., & Reddy, A. R. (2017). Physiological and molecular insights into the high salinity tolerance of Pongamia pinnata (L.) pierre, a potentil biofuel tree species. *Plant Sci., 258*, 102–111.

Matsushita, N., & Matoh, T. (1991). Characterization of Na + exclusion mechanisms of salt-tolerant reed plants in comparison with salt-sensitie rice plants. *Physiol. Plant, 83*, 170–176. doi: 10.1111/j.1399-3054.1991.tb01298.x.

Digitized by Sam Jonah Library

Mattioli, R., Palombi, N., Funck, D., & Trovato, M. (2020). Proline Accumulation in Pollen Grains as Potential Target for Improved Yield Stability Under Salt Stress. *Frontiers in Plant Science, 11*, 582877. doi:htts://doi.org/10.3389/fpls.2020.582877

McNear Jr., D. H. (2013) The Rhizosphere - Roots, Soil and Everything In Between. *Nature Education Knowledge* 4(3):1

Mehari, A., Ericsson, T., & Weih, M. (2005). Effects of NaCl on seedling growth, biomass productin and water status of Acacia nilotia and A. tortiis. *J. Arid Environ., 62*(2), 343–349.

Mendoza-González, G., Martínez, M., & Lithgow, D. (2014). Biological Flora of Coastal Dunes and Wetlands: Canavalia rosea (Sw.) DC. *Journal of Coastal Research*. doi:10.2112/JCOASTRES-D-13-00106.1

Meng, X., Zhou, J., & Sui, N. (2018). Mechanisms of Salt Tolerance in Halophytes: Current Understanding and Recent Advances. *Open Life Sciences, 13*, 149–154. doi: htts://doi.org/10.1515/biol-2018-0020

Mensah, A. K., Mahiri, I. O., Owusu, O., Mireku, O. D., Wireko, I., & Kissi, E. A. (2015). Environmental Impacts of Mining: A Study of Mining Communities in Ghana. *Applied Ecology and Environmental Sciences, 3*, 81-94.

Messedi, D., Labidi, N., Grignon, C., & Abdelly, C. (2004). Limits imposed by salt to the growth of the halophyte Sesuvium portulacastrum. *J. Plant Nutr. Soil Sci., 167*, 720–725. doi:10.1002/jpln.200420410

Mokrani, S., Nabti, E.-h., & Cruz, C. (2022). Recent Trends in Microbial Approaches for Soil Desalination. *Applied Sciences, 12*(7), 3586. doi: https://doi.org/10.3390/app12073586

Montero, E., Francisco, A. M., Montes, E., & Herrera, A. (2018). Salinity induction of recycling Crassulacean acid metabolism and salt tolerance in plants of Talinum triangulare. *Annals of Botany, 121*, 1333–1342.

Moore, M. (2024, 21, 03). *How to Heat Your Greenhouse Cheaply*. Retrieved from Greenhouse Solar Heating. https://www.greenhousecatalog.com/greenhouse-solar-heating#:~:text=Greenhouses%20harness%20the%20light%20and,sunlight%20and%20warms%20the%20earth.

Morgan, J. B. & Connolly, E. L. (2013) Plant-Soil Interactions: Nutrient Uptake. *Nature Education Knowledge* 4(8):2

Morris, J. B. (2023). Multiariate Analysis of Buttrfl Pea (Clitoria ternatea L.) Genotypes With Potentially Healthy Nutraceutials and Uses. *Journal of dietary supplements, 20*(3), 475–484.

Digitized by Sam Jonah Library

Moseki, B., & C, Buru J. (2010). Ionic and water relations of Sesuvium portulacastrum (L). *Scient. Res. Ess., 5*, 35–40.

Mouafon, I. L., Tiani, G. L., Mountessou, B. Y., Lateef, M., Ali, M. S., Green, I. R. & Kouam S. F. (2021). Chemical constiuents of the medicinal plant Indigofera spicata Forsk (Fabaceae) and their chemopheneti signifiance. *Biochemical Systematis and Ecology, 95*, 104230.

Muchate, N. S., Nikalje, G., Rajurkar, N. S., Suprasanna, P., & Nikam, T. D. (2016). Physiological responses of the halophyte Sesuvium portulacastrum to salt stress and their relevance for saline soil bio-reclamatin. *Flora, 224*, 96–105.

Munns, R. (2002). Comparative physiology of salt and water stress. *Plant Cell Environ., 25*, 239–50.

Munns, R. (2005). Genes and salt tolerance: bringing them together. *New Phytol., 167*, 645– 63.

Munns, R., & Gilliham, M. (2015). Salinity tolerance of crops–what is the cost? *New Phytologist, 208*(3), 668-673.

Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology, 59*, 651–681.

Munns, R., James, R. A., & Läuchli, A. (2006). Approaches to increasing the salt tolerance of wheat and other cereals. *J. Exp. Bot., 57*, 1025–1043. doi: 10.1093/jxb/erj100

Naamala, J., & Smith, D. (2021). Microbial Derived Compounds Are a Promising Approach to MitiatigSalinity Stress in Agricultural Crops. *Front. Microbiol., 12*(765320). doi:10.3389/fmicb.2021.765320

Nabati, J., Ahmadi-Lahijani, M. J., Goldani, M., Nezami, A., Oskoueian, A., Hosinaiyan, M., & Mohammadi, M. (2021). Lowering medium pH improves tolerance of tomato (Lycopersicon esculentum) plants to long-term salinity exposure. *Journal of Plant Nutrition, 44*, 1853 - 1868.

Nadkarni, A. K. (1954). *Indian materia medica* (3 ed.). Bombay: Popular Books.

Naidu, P. P., & Rajesh, B. (2014). *Pupalia lappacea* juss [l]: a review of phytochemistry and therapeutic application. *Asian Journal of Pharmaceutial and Clinical Research, 7*(6), 15–18.

Najafian, S. H., Rahemi, M., & Travallali, V. (2008). Effect of Salinity on Tolerance of Two Bitter Almond Rootstocks. *Am.-Eura. J. of Agric. Environ., 3*, 264–268.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Navarrete, A. M., Torres, E. A., & Cariño, R. (2021). Kalanchoe daigremontina: functinal propertis and histopathological effcts on Wistar rats under hyperglycemia-inducing diet. *Indian J. Pharm Educ. J., 55*, 445–54.

Naz, N., Hameed, M., Ashraf, M., Al-Qurainy, F., & Arshad, M. (2010). Relatinships between gas-exchange characteristis and stomatal structural modifiatins in some desert grasses under high salinity. *Photosynthetia, 48*(3), 446–456. doi:10.1007/s11099-010-0059-7

Negrão, S., Schmöckel, S. M., & Tester, M. J. (2017). Evaluating physiological responses of plants to salinity stress. *Annals of botany, 119*(1), 1-11.

Netondo, G., Onyango, J., & Beck, E. (2004). Sorghum and salinity: II. Gas exchange and chlorophyll fluorescence of sorghum under salt stress. *Crop Science, 44*, 806–811.

Nikalje, G. C., Srivastava, A. K., Pandey, G. K., & Suprasanna, P. (2018). Halophytes in biosaline agriculture: Mechanism, utilization, and value addition. *Land Degradation & Development, 29*(4), 1081–1095.

Nizam, I. (2011). Effects of salinity stress on water uptake, germination and early seedling growth of perennial ryegrass. *African Journal of Biotechnology, 10*(51), 10418-10424.

Nosetto, M. D., Acosta, A. M., Jayawickreme, D. H., Ballesteros, S., Jackson, R. B., Gampel, J., & GabrielIcon, E. (2013). Land-use and topography shape soil and groundwater salinity in central Argentina. *Elsevier; Agricultural Water Management, 129*(1), 120-129.

Nouairi, I., Ghnaya, T., Youssef, N. B., Zarrouk, M., & Ghorbel, M. H. (2006). Changes in content and fatty acid profiles of total lipids of two halophytes: Sesuvium portulacastrum and Mesembryanthemum crystallinum under cadmium stress. *J. Plant Physiol., 163*, 1198– 1202. doi:10.1016/j.jplph.2005.08.020

Obi, R. K., Iroagba, I. I., & Ojiako, O. A. (2006). Virucidal potential of some edible Nigerian vegetables. *Afr. J. Biotechnol., 5*, 1785–8.

Obiefuna, G. I., & Orazulike, D. M. (2011). The Hydrochemical Characteristics and Evolution of Groundwater in Semiarid Yola Area, Northeast, Nigeria. Research Journal of Environmental and Earth Sciences, 3(4), 400-416. https://www.airitilibrary.com/Article/Detail?DocID=20410492-201106-201507240032-201507240032-400-416

O'Leary, J. W. (1988). Saline Environments and Halophytic Crops. In E. E. Whitehead, C. F. Hutchinson, B. N. Timmerman, & R. G. Varady, *Arid Lands, Today and Tomorrow* (p. 773). Boulder, Colorado: West view Press.

Digitized by Sam Jonah Library

Ololade, Z. S., Kuyooro, S. E., Ogunmola, O. O., & Abiona, O. O. (2017). Phytochemical, antioxidant, anti-arthritic, anti-inflammatory and bactericidal potentials of the leaf extract of Lactuca teraxacifolia. *Glob. J. Med. Res., 17*(2), 1–7.

Orsini, F., Accorsi, M., Gianquinto, G., Dinelli, G., Antognoni, F., Carrasco, K. B. & Bosi, S. (2011). Beyond the ionic and osmotic response to salinity in Chenopodium quinoa: functinal elements of successful halophytim. *Funct. Plant Biol., 38*(10), 818–831. doi:10.1071/FP11088

Orzechowska, A., Trtíek, M., Tokarz, K. M., Szymańska, R., Niewiadomska, E., Rozpądek, P., & Wątor, K. (2021). Thermal Analysis of Stomatal Response under Salinity and High Light. *Internatinal Journal of Molecular Sciences, 22*(9), 4663. doi:htts://doi.org/10.3390/ijms22094663

Othman, B. A., Ellouzi, H., Planchais, S., De Vos, D., Faiyue, B., Carol, P., . . . Savouré, A. (2017). Phospholipases Dζ1 and Dζ2 have distinct roles in growth and antioxidant systems in Arabidopsis thaliana responding to salt stress. *Planta, 246*(4), 721 -735. doi:10.1007/s00425-017-2728-2

Palchett, M. V., Reginato, M., Llanes, A., Hornbacher, J., Papenbrock, J., Barboza, G. E. & Cantero, J. J. (2021). New insights into the salt tolerance of the extreme halophyti species Lycium humile (Lycieae, Solanaceae). *Plant Physiol. Biochem., 163*, 166–177.

Panda, A., Rangani, J., & Parida, A. (2019). Cross talk between ROS homeostasis and antixidatie machinery contributes to salt tolerance of the xero-halophyte Haloxylon salicornicum. *Environ. Exp. Bot., 166*, 103799.

Pandjaitan, N., Howard, L. R., Morelock, T., & Gil, M. I. (2005). Antioxidant capacity and phenolic content of spinach as affected by genetics and maturation. *J. Agric. Food Chem., 53*, 8618–8623.

Park, J., Okita, T. W., & Edwards, G. E. (2009). Salt tolerant mechanisms in single-cell C4 species Bienerti sinuspersici and Suaeda aralocaspica (Chenopodiaceae). *Plant Science, 176*, 616-626.

Parker, C. (2022). Paspalum vaginatum (seashore paspalum). *CABI Compendium*.

Pavithra, M., Sridhar, K. R., & Greeshma, A. A. (2017). Bioactive attibutes of traditional leafy vegetable Talinum triangulare. In *Handbook of nutritin in heart health* (pp. 1-4). Wageningen Academic Publishers.

Payne, W. J. (1956). Ipomoea reptans Poir a useful tropical fodder plant. *Trop. Agric. Trin., 33*, 302–305.

Paz, A., Hristov, B., Amezketa, E., Falsone, G., Zambujo, J., & Canfora, L. (2020). Minipaper: Prevention, Mitigation and Adaptation Strategies for Soil

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Salinisation at Farm Level. Brussels:. *EIP-AGRI Focus Group Soil salinization*. Retrieved from EIP-AGRI Focus Group Soil salinization: https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/fg36_ minipaper_preventinomitigationadaptation_2020_en.pdf.

Pearson, K. E., & Bauder., J. W. (2006). The Basics of Salinity and Sodicity Effects on Soil Physical Properties. *MSU Extension Water Quality Program*.

Peng, Z., He, S., & Sun, J. (2016). Na + compartmentalizatin related to salinity stress tolerance in upland cottn (Gossypium hirsutum) seedlings. *Sci. Rep., 6*, 34548. doi: htts://doi.org/10.1038/srep34548

Perry, L. M., & Metzger, J. (1980). *Medicinal plants of east and Southeast Asia: attributed properties and uses.* Cambridge, MA: MIT Press.

Pessarakli, M. (2018). Screening various cultivars of seashore paspalum (Paspalum vagenitum Swartz) for salt tolerance for potential use as a cover plant in in combatting desertification. *Int. J. Water Resour. Arid Environ., 7*, 36–43.

PFAF (2024). *Plants For A Future*. Retrieved from Furcraea cabuya - Trel.: https://pfaf.org/user/Plant.aspx?LatinName=Furcraea+cabuya#:~:text=boo k%20from%20PFAF.-,Other%20Uses,succulent%20gardens%20or%20 Mediterranean%20gardens.

Pham, L. J. (2016). Coconut (cocos nucifera). In *Industrial oil crops* (pp. 231-242). AOCS Press.

Pitman, M., & Läuchli, A. (2002). Global Impact of Salinity and Agricultural Ecosystems. In A. Läuchli, & U. Lüttge, *Salinity: Environment - Plants - Molecules* (pp. 3–20). Dordrecht: Springer.

Plaut, Z., Edelstein, M., & Ben-Hur, M. (2013). Overcoming Salinity Barriers to Crop Productin Using Traditinal Methods. *Critial Reviews in Plant Sciences, 32*(4), 250-291.

Pompeiano, A., Di Patrizio, E., Volterrani, M., Scartazza, A., & Guglielminetti, L. (2016). Growth responses and physiological traits of seashore paspalum subjected to short-term salinity stress and recovery. *Agr. Water Manage, 163*, 57–65. doi:10.1016/j.agwat.2015.09.004

Popova, V., Stoyanova, A., & Mazova, N. (2020). Phytochemical compositin and biological actiity of Physalis spp.: A mini-review. *Food Science and Applied Biotechnology*.

Pushpavalli, R., Quealy, J., Colmer, T. D., Turner, N. C., Siddique, K. H., Rao, M. V., & Vadez, V. (2016). Salt stress delayed flowering and reduced reproductive success of chickpea (Cicer arietinum L.), a response associated

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

with Na+ accumulation in leaves. *Journal of Agronomy and Crop Science, 202*(2), 125-138.

Qadir, M., Quillérou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R. J., . . . Noble, A. D. (2014). Economics of Salt-Induced Land Degradation and Restoration. *Natural Resources Forum, 38*, 282-295. doi:https://doi.org/10.1111/1477-8947.12054

Quichimbo, E., Singer, M., & Cuthbert, M. (2020). Characterising Groundwater-Surface Water Interactions in Idealised Ephemeral Stream Systems. *Hydrol. Process., 34*, 3792–3806.

Qureshi, A. S., Qadir, M., H. N., Turral, H., & Javadi, A. (2007). A Review of Management Strategies for Salt-Prone Land and Water Resources in Iran.Colombo, Sri Lanka. *International Water Management Institute*, 30.

Rabhi, M., Ferchichi, S., Jouini, J., Hamrouni, M. H., Koyro, H. W., Ranieri, A., . . . Smaoui, A. (2010b). Phytodesalination of a salt-affected soil with the halophyte Sesuvium portulacastrum L. to arrange in advance the requirements for the successful growth of a glycophytic crop. *Bioresour. Technol., 101*, 6822-6828.

Rabhi, M., Hafsi, C., Lakhdar, A., Hajji, S., Barhoumi, Z., Hamrouni, M. & Smaoui, A. (2009). Evaluation of the capacity of three halophytes to desalinize their rhizosphere as grown on saline soils under nonleaching conditions. *Afr. J. Ecol., 47*, 463–468.

Rabhi, M., Karray-Bouraoui, N., Medini, R., Attia, H., Athar, H., Lachaâl, M., . . . Smaoui, A. (2010a). Seasonal variations in the capacities of phytodesalination of a salt-affected soil in two perennial halophytes in their natural biotope. *J. Biol. Res., 14*, 181-189.

Rady, M., Kusvuran, A., Alharby, H. F., Alzahrani, Y., & Kusvuran, S. (2019). Pretreatment with proline or an organic bio-stiulant induces salt tolerance in wheat plants by improving antioxidant redox state and enzymatic activities and reducing the Oxidatie stress. *J. Plant Growth Regul., 38*, 449–462. doi: 10.1007/s00344-018-9860-5

Rai, U. N., & Sinha, S. (2001). Distributin of metals in aquati edible plants: Trapa natans (Roxb.) Makinoand Ipomoea aquatia Forsk. . *Environmental monitoring and assessment, 70*(3), 241–252. doi:htts://doi.org/10.1023/a:1010727325662

Ramani, B. (2004c). *Investigation of salt tolerance mechanisms in the halophytes Aster tripolium L. and Sesuvium portulacastrum L. through physiological, biochemical and molecular methods.* Austria: A Ph. D. thesis, Institut fur Botanik.

Digitized by Sam Jonah Library

Ramani, B., Papenbrock, J., & A, S. (2004b). Connecting sulfur me- tabolism and salt tolerance mechanisms in the halophytes Aster tripolium and Sesuvium portulacastrum. *Trop. Ecol., 45*, 173–182.

Ramani, B., Papenbrock, J., & Zorn, H. (2004a). Quantification and fatty acid profiles of sulfolipids in two halophytes and a glycophyte grown under different salt concentrations. *Z. Natu., 59c*, 835–842.

Ramani, B., Reeck, T., Debez, A., Stelzerd, R., Huchzermeyera, B., Schmidt, A., & Papenbrock, J. (2006). Aster tripolium L. and Sesuvium portu- lacastrum L.: two halophytes, two strategies to survive in saline habitats. *Plant Physiol. Biochem., 44*, 395–408. doi:10.1016/ j.plaphy.2006.06.007

Rangani, J., Parida, A. K., & Panda, A. (2016). Coordinated changes in antioxidative enzymes protect the photosynthetic machinery from salinity induced oxidative damage and confer salt tolerance in an extreme halophyte Salvadora persica L. *Frontiers in Plant Science, 7*, 172160.

Ravindran, K. C., Venkatesan, K., Balakrishnan, V., Chellappan, K. P., & Balasubramani, T. (2007). Restoration of saline land by halophytes. *Soil Biol. Biochem., 39*, 2661-2664.

Redondo-Gómez, S., Mateos-Naranjo, E., Davy, A. J., Fernández-Muñoz, F., Castellanos, E. M., Luque, T., & Figueroa, M. E. (2007). Growth and photosyntheti responses to salinity of the salt-marsh shrub Atriplex portulacoides. *Ann. Bot., 100*(3), 555–563. doi: 10.1093/aob/mcm119

Reguera, E. d., Veatch, J., Gedan, K., & Tully, K. L. (2020). The effects of saltwater intrusion on germinatin success of standard and alternatie crops. *Environmental and Experimental Botany, 180*, 104254. doi: https://doi.org/10.1016/j.envexpbot.2020.104254

Rezapour, S., Nouri, A., Asadzadeh, F., Barin, M., Erpul, G., Jagadamma, S., & Qin, R. (2023). Combining chemical and organic treatments enhances remediation performance and soil health in saline-sodic soils. *Communications Earth & Environment, 4*(1), 285.

Rhoades, J. (1996). Salinity: Electrical Conductivity and Total Dissolved Solids. In *Sparks, R.L., Ed., Methods for Soil Analysis, Part 3: Chemical Methods* (pp. 417-435). Madison: Soil Science Society of America.

Riefner, R. E., & Columbus, J. T. (2008). *Paspalum vaginatum* (poaceae), a new threat to wetland diversity in southern california. *Journal of the Botanical Research Institute of Texas, 2*(1), 743-759.

Robin, A. H., Matthew, C., Uddin, M. J., & Bayazid, K. N. (2016). Salinity-induced reduction in root surface area and changes in major root and shoot traits at

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

the phytomer level in wheat. *Journal of Experimental Botany, 67*(12), 3719-3729.

Rodríguez-Rodríguez, A. Í., Gonz Soto, M. Á., Hern Hernndez, L. Á., Jim Mendoza, C. É., Ortega González, M. J., & Padr Padrón, P. Ó. (1993). Assessment of Soil Degradation in the Canary Islands (Spain). *Land Degrad. Dev., 4*, 11–20.

Roi, J. (1955). *Treatise on Chinese medicinal plants.* Paris: Paul Lechevalier.

Rojas, H. A. (2010). Plantas empleadas en medicina tradicional en Tierra Caliente, Guerrero, México, para el tratamiento de enfermedades infecciosas. *Revista Colombiana de Ciencia Animal Recia, 2*, 124-136.

Romero-Aranda, R., Soria, T., & Cuartero, J. (2001). Tomato plant-water uptake and plant-water relationships under saline growth conditions. *Plant Science, 160*(2), 265-272.

Rozema, J. C., Broekman, R., Ji, B., & van Bodegom, P. (2015). Comparing salt tolerance of beet cultivars and their halophytic ancestor: consequences of domestication and breeding programmes. *AoB Plants, 7*, plu083.

Rozema, J., & Flowers, T. (2008). Crops for a salinized world. *Science*, 1478–1480.

Rusydi, A. F. (2018). Correlation between conductivity and total dissolved solid in various type of water: A review. In *IOP conference series: earth and environmental science* (Vol. 118, p. 012019). IOP publishing.

Sabovljevic, M., & Sabovljevic, A. (2007). Contribution to the coastal bryophytes of the Northern Mediterranean: Are there halophytes among bryophytes. *Phytologia balcanica, 13*(2), 131-135.

Saddhe, A. A., Malvankar, M. R., Karle, S. B., & Kumar, K. (2019). Reactive nitrogen species: Paradigms of cellular signaling and regulation of salt stress in plants. *Environmental and Experimental Botany, 161*, 86–97.

Saddiq, M. S., Iqbal, S., Hafeez, M. B., Ibrahim, A. M., Raza, A., Fatima, E. M. & Ciarmiello, L. F. (2021). Effect of salinity stress on physiological changes in winter and spring wheat. *Agronomy, 11*(6), 1193.

Sáenz-Mata, J., Palacio-Rodríguez, R., Sánchez-Galván, H., & Balagurusamy, N. (2016). Plant Growth Promoting Rhizobacteria Associated to Halophytes: Potential Applications in Agriculture. In M. Khan, B. Boër, M. Ȍzturk, M. Clüsener-Godt, B. Gul, & S. Breckle, *Sabkha Ecosystems: Tasks for Vegetation Science* (Vol. 48). Cham: Springer. doi:https://doi.org/10.1007/978-3-319-27093-7_24

Sahayaraj, K., & Sathyamoorthi, P. (2010). The toxicity and biological effct of Pedalium murex L. extracts on the tobacco cutworm, Spodoptera litura

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

(Fabr.) larvae. *Archives of Phytopathology and Plant Protectin, 43*, 1768 - 1780.

Sakpere, A. M., & Aremu, O. A. (2008). The Growth of Launaea taraxacifolia (Asteraceae) and its Response to Shading. *Research Journal of Botany, 3*(2), 90-96.

Sakr, M. T., El-Sarkassy, N. M., & Fuller, M. P. (2015). Minimization the effects of salt stress on sweet pepper plants by exogenous protectants application. *ZagaZig Journal of Agricultural Botany, 42*(6), 1397-1410.

Samuelsson, G., Farah, M. H., & Claeson, P. (1992). Inventory of plants used in traditional medicine in Somalia II plants of the families Combretaceae to Labiatae. *J. Ethnopharmacol., 37*, 47–70.

Schiavon, M., Leinauer, B., Serena, M., Sallenave, R., & Maier, B. (2012). Bermudagrass and seashore paspalum establishment from seed using differing irrigation methods and water qualities. *Agron. J., 104*, 706–714. doi:10.2134/ agronj2011.0390

Schleiff, U. (2008). Analysis of water supply of plants under saline soil conditions and conclusions for research on crop salt tolerance. *Journal of Agronomy and Crop Science, 194*(1), 1-8.

Sengbusch, P. v. (2003). Halophytes. *Botanik Online, University of Hamburg*.

Sepehr, M. F., & Ghorbanli, M. (2006). Physiological responses of Zea mays seedlings to interactions between cadmium and salinity. *Journal of Integrative Plant Biology, 48*(7), 807-813.

Serag, M. (1999). Ecology of Four Succulent Halophytes in the Mediterranean Coast of Damiett Egypt. *Estuarine, Coastal and Shelf Science, 49*, 29-36.

Shabala, S. (2013). Learning from halophytes: physiological basis and strategies to improve abioti stress tolerance in crops. *Annals of Botany, 112*(7), 1209–1221. doi: htts://doi.org/10.1093/aob/mct205

Shabala, S., & Pottosin, I. (2014). Regulation of potassium transport in plants under hostile conditions: implications for abiotic and biotic stress tolerance. *Physiol. Plant, 151*, l257–l279.

Shahba, M. A., Alshammary, S. F., & Abbas, M. S. (2012). Effects of salinity on seashore paspalum cultivars at different mowing heights. *Crop Science, 52*, 1358–1370. doi:10.2135/cropsci2011.06.0337

Shahid, S. A., Zaman, M., & Heng, L. (2018). Salinity and Sodicity Adaptation and Mitigation Options. In M. Zaman, S. A. Shahid, & L. Heng, *Guideline for Salinity Assessment, Mitigation and Adaptation Using Nuclear and Related*

Digitized by Sam Jonah Library

Techniques (pp. 55–89). Vienna: International Atomic Energy Agency. doi:doi:10.1007/978-3-319-96190-3_3

Shan, Z., Zhou, S., Shah, A., Arafat, Y., Arif Hussain Rizvi, S., & Shao, H. (2023). Plant Allelopathy in Response to Biotic and Abiotic Factors. *Agronomy*, *13*(9), 2358.

Shao, Q., Han, N., Ding, T. L., Zhou, F., & Wang, B. S. (2014). SsHKT1;1 is a potassium transporter of the C-3 halophyte Suaeda salsa that is involved in salt tolerance. *Funct. Plant Biol.,, 41*, 790-802.

Sharipova, G., Ivanov, R., Veselov, D., Akhiyarova, G., Seldimirova, O., Galin, I. & Kudoyarova, G. (2022). Effect of Salinity on Stomatal Conductance, Leaf Hydraulic Conductance, HvPIP2 Aquaporin, and Abscisic Acid Abundance in Barley Leaf Cells. *Internatinal Journal of Molecular Sciences, 23*(22), 14282. doi:htts://doi.org/10.3390/ijms232214282

Sharma, R., Wungrampha, S., Singh, V., Pareek, A., & MK., S. (2016). Halophytesas bioenergy crops. *Frontiers in Plant Science, 7*(1372).

Shaygan, M., & Baumgartl, T. (2022). Reclamation of salt-affected land: A review. *Soil Systems, 6*(3), 61.

Shekhar, S., Rathur, R., Singh, R. P., & Kumar, A. (2021). Pedalium murex L.: Potential genetic resource for herbal medicine and mucilage.

Shin, K. Y., Bhandari, R. S., & Lee, G. J. (2021). Monitoring of Salinity, Temperature, and Drought Stress in Grafted Watermelon Seedlings Using Chlorophyll Fluorescence. *Frontiers of Plant Science, 12*, 786309. doi:10.3389/fpls.2021.786309

Shrivastava, P., & Kumar, R. (2015). Soil Salinity: A Serious Environmental Issue and Plant Growth Promoting Bacteria as One of the Tools for its Alleviation. *Saudi J. Biol. Sci., 22*, 123–131. doi:10.1016/j.sjbs.2014.12.001

Sial, R., Chaudhary, M., Abbas, S., Latif, M., & Khan, A. (2006). Quality of effluents from hattar industrial estate. *J. Zhejiang Univ. Sci. B, 7*(12), 974–980. doi:10.1631/jzus.2006.B0974

Simpson, C. R., Franco, J. G., King, S. R., & Volder, A. (2018). Intercropping halophytes to mitigate salinity stress in watermelon. *Sustainability*, *10*(3), 681.

Singh, J. S., Pandey, V. C., Singh, D. P., & Singh, R. P. (2010). Influence of pyrite and farmyard manure on population dynamics of soil methanotroph and rice yield in saline rain-fed paddy field. *Agriculture, ecosystems & environment*, *139*(1-2), 74-79.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Singh, K. N., & Chatrath, R. (2001). Salinity tolerance. In M. Reynolds, J. Monasterio, & A. McNab, *Application of Physiology in Wheat Breeding* (pp. 101–110). Mexico: CIMMYT.

Siriphanich, J., Saradhuldhat, P., Romphophak, T., Krisanapook, K., Pathaveerat, S., & Tongchitpakdee, S. (2011). Coconut (Cocos nucifera L.). In *Postharvest biology and technology of tropical and subtropical Fruits* (pp. 8-35). Woodhead Publishing.

Slama, I., Abdelly, C., Bouchereau, A., Flowers, T., & Savoure´, A. (2015). Diversity, distribution and roles of osmoprotective compounds accumulated in halo- phytes under abiotic stress. *Annals of Botany, 115*, 433–447.

Slama, I., Ghnaya, T., Hessini, K., Messedi, D., Savoure, A., & Abdelly, C. (2007c). Comparative study of the effects of mannitol and PEG osmotic stress on growth and solute accumulation in Sesuvium portulacastrum. *Environ. Expt. Bot., 61*, 10–17. doi:10.1016/ j.envexpbot.2007.02.004

Slama, I., Ghnaya, T., Messedi, D., Hessini, K., Labidi, N., Savoure, A., & Abdelly, C. (2007b). Effect of sodium chloride on the response of the halophyte species Sesuvium portulacastrum grown in mannitol-induced water stress. *J. Plant Res., 120*, 291–299. doi:10.1007/s10265-006-0056-x

Slama, I., Ghnaya, T., Savouŕe, A., & Abdelly, C. (2008). Combined effects of long-term salinity and soil drying on growth, water relations, nutrient status and proline accumulation of Sesuvium portulacastrum. *C. R. Biol., 331*, 442–451. doi:10.1016/j.crvi.2008.03.006

Slama, I., Messedi, D., Ghnaya, T., Savouŕe, A., & Abdelly, C. (2006). Effects of water-deficit on growth and proline metabolism in Sesuvium portulacastrum. *Environ. Exp. Bot., 56*, 231–238. doi:10.1016/ j.envexpbot.2005.02.007

Slama, I., Messedi, D., Ghnaya, T., Savouŕe, A., & Abdelly, C. (2007a). Effect ofsodium chloride on the response ofthe halophyte species Sesuvium portulacastrum grown in mannitol-induced water stress. *J. Plant Res., 120*, 291–299. doi:10.1007/s10265-006-0056-x

Song, L., Ding, R., Du, T., Kang, S., Tong, L., Xue, F., & Wei, Z. (2023). Stomatal conductance parameters of tomatoes are regulated by reducing osmoti potentil and pre-dawn leaf water potentil via increasing ABA under salt stress. *Environmental and Experimental Botany, 206*, 105176. doi:htts://doi.org/10.1016/j.envexpbot.2022.105176

Srivastava, N. (2020). Reclamation of saline and sodic soil through phytoremediation. In Environmental concerns and sustainable development. *Springer*, 279–306.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Srivastava, S. (2022). Morpho-Anatomical Adaptation against Salinity. *Plant Defense Mechanisms*, 187.

Stavi, I., Thevs, N., & Priori, S. (2021). Soil Salinity and Sodicity in Drylands: A Review of Causes, Effects, Monitoring, and Restoration Measures. *Frontiers in Environmental Science, 9*, 1-16. doi:10.3389/fenvs.2021.712831

Steiner, M. (1935). Die Pflanzengesellschaften der Salzmarschen in den nordöstlichen Vereinigten Staaten von Nordamerika.

Stewart, G. R., & Lee, J. A. (1974). The Role of Proline Accumulatin in Halophytes. *Planta, 120*(3), 279-289. doi: htts://www.jstor.org/stable/23371075

Suarna, I. W., & Wijaya, I. M. (2021). Butterfly Pea (Clitoria ternatea L.: Fabaceae) and Its Morphological Variations in Bali. *Journal of Tropical Biodiversity and Biotechnology*.

Sulian, L., Jiang, P., Chen, X., Fan, P., Wang, X., & Li, Y. (2012). Multiple compartmentalization of sodium conferred salt tolerance in Salicornia europaea. *Plant Physiology and Biochemistry, 51*, 47-52. doi:htts://doi.org/10.1016/j.plaphy.2011.10.015.

Sun, R., Wang, X., Tian, Y., Guo, K., Feng, X., Sun, H. & Liu, B. (2022). Long-term amelioration practices reshape the soil microbiome in a coastal saline soil and alter the richness and vertical distribution differently among bacterial, archaeal, an. *Frontiers in Microbiology, 12*, 768203. doi:10.3389/fmicb.2021.768203

Suriani, D. N., & Talanca, A. (2019). Correlation Of Stomata Density To Rust Severity on Some Accessions of Maize Germplasm. *Journal Hama Dan Penyakit Tumnuhan Tropika*.

Sverdrup, H., & Warfvinge, P. (1988). Weathering ofPrimary Silicate Minerals in the Natural Soil Environment in Relation to a Chemical Weathering Model. *Water Air Soil Pollution, 38*, 387–408.

Swaine, M. D., Okali, D. U., Hall, J. B., & Lock, J. M. (1979). Zonation of a Coastal Grassland in Ghana, West Africa. *Folia Geobotanica & Phytotaxonomica, 14*(1), 11-27. Retrieved from https://www.jstor.org/stable/4180070

Swarna, J., & Ravindhran, R. (2013). In vitro organogenesis from leaf and transverse thin cell layer derived callus cultures of Talinum triangulare (Jacq.) Willd. *Food Chemistry, 70*, 79–87.

Swarna, J., Ravindhran, R., & Lokeswari, T. S. (2015). Characterization of Talinum triangulare (Jacq.) Willd. germplasm using molecular descriptors. *South African Journal of Botany, 97*, 59–68.

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Synder, G. H., & Morton. J. F: Genung, W. G. (1981). Trials of Ipomoea aquatic nutritious vegetable with high protein and nitrate extraction potential. *Proc. Fla. State. Hortic. Soc., 94*, 230–235.

Szabolcs, I. (1989). *Salt Affected Soils.* Boca Raton: CRC Press.

Székely, G., Ábrahám, E., Cséplő, Ã., Rigó, G., Zsigmond, L., & ... Csiszár, J. (2008). Duplicated P5CS genes of Arabidopsis play distinct roles in stress regulation and developmental control of proline biosynthesis. *Plant J., 53*, 11–28. doi:10.1111/j.1365-313X.2007.03318.x

Tang, X., Zhang, H., Shabala, S., Li, H., Yang, X., & Zhang, H. (2020). Tissue tolerance mechanisms conferring salinity tolerance in a halophyti perennial species Nitraria sibirica Pall. *Tree Physiol.* .

Taratima, W., Chomarsa, T., & Maneerattanarungroj, P. (2022). Salinity Stress Response of Rice (Oryza sativa L. cv. Luem Pua) Calli and Seedlings. *Scientifica*, 5616683. doi:https://doi.org/10.1155/2022/5616683

Taras, M.J., Greenberg, A.E., Hoak, R.D. and Rand, M.C. (Editors), 1975. Standard methods for the examination of water and wastewater. American Public Health Assoc., USA, 14th edn., pp. 613-614.

Tedeschi, A., Schillaci, M., & Balestrini, R. (2023). Mitigating the impact of soil salinity: recent developments and future strategies. *Italian Journal of Agronomy, 18*(2173). doi:10.4081/ija.2023.2173

Tejera, T. A., Sousi, M., & Lluch, C. (2006). Physiological and nutritional indicators of tolerance to salinity in chickpea plants growing under symbiotic conditions. *Environmental and Experimental Botany, 58*, 17 – 24.

Tester, M., & Davenport, R. (2003). Na+ tolerance and Na+ transport in higher plants. *Ann. Bot., 91*, 503–527.

Thiam, S., Villamor, G. B., Faye, L. C., Sène, J. H., Diwediga, B., & Kyei-Baffour, N. (2021). Monitoring Land Use and Soil Salinity Changes in Coastal Landscape: A Case Study from Senegal. *Environmental Monitoring and Assessment, 193*. Retrieved from https://link.springer.com/article/10.1007/s10661-021-08958-7

Thomas, M. I., & Saunders, R. A. (1974). An inexpensive system of automated flame photometry of serum sodium and potassium. *Annals of clinical biochemistry, 11*(6), 238–241. doi:https://doi.org/10.1177/000456327401100169

Tiamiyu, A. M., Okocha, R. C., Okunlade, O. A., Olatoye, I. O., & Adedeji, O. B. (2023). Phytochemical Constituents, Nutritional and Antibacterial

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Potentials of Selected Medicinal Plants (Allium sativum, Chromolaena odorata, and Talinum triangulare). *Majalah Obat Tradisional*.

Topp, G. C., Parkin, G. W., Ferré, T. P., Carter, M. R., & Gregorich, E. G. (2008). Soil water content. *Soil sampling and methods of analysis*, *2*, 939-962.

Tran, D., Konishi, A., Cushman, J., Morokuma, M., Toyota, M., & Agarie, S. (2019). Ion accumulatin and expression of ion homeostasisrelated genes associated with halophilism, NaCl-promoted growth in a halophyte Mesembryanthemum crystallinum L. *Plant Prod. Sci., 23*, 91–102.

Tripathi, S., Sharma, P., Singh, K., Purchase, D., & Chandra, R. (2021). Translocation of heavy metals in medicinally important herbal plants growing on complex organometallic sludge of sugarcane molasses-based distillery waste. *Environmental Technology and Innovation, 22*. doi:https://doi.org/10.1016/j.eti.2021.101434

Tseng, C. F., Iwakami, S., & Mikajiri, A. (1992). Inhibition of in vitro prostaglandin and leukotriene biosynthesis by cinnamoyl-betaphenethylamine and N-acyldopamine derivatives. *Chem. Pharm. Bull, 40*(2), 396–400.

Turcios, A., Cayenne, A., Uellendahl, H., & Papenbrock, J. (2021). Halophyte Plants and Their Residues as Feedstock for Biogas Production—Chances and Challenges. *Appl. Sci., 11*, 2746. doi:https: //doi.org/10.3390/ app11062746

Uchiyama, T., Saito, S., Yamanashi, T., Kato, M., Takebayashi, K., Hamamoto, S., &Uozumi, N. (2023). The HKT1 Na+ transporter protects plant fertility by decreasing Na+ content in stamen filaments. *Science Advances, 9*(22), eadg5495. doi:htts://doi.org/10.1126/sciadv.adg5495

United Nations World Water Development. (2015). *Water for a sustainable world.* Unesco. Retrieved 8 29, 2017, from http://unesdoc.unesco.org/images/ 0023/002318/231823E.pdf

United Nations-Department of Economic and Social Affairs. (2019). *Population.* New York: United Natons, Department of Economic and Social Afairs.

van Der Velde, M., Goëau, H., Bonnet, P., d'Andrimont, R., Yordanov, M., Affouard, A., ... & Joly, A. (2023). Pl@ ntNet Crops: merging citizen science observations and structured survey data to improve crop recognition for agri-food-environment applications. Environmental Research Letters, 18(2), 025005.

Vasconcellos, M. C., Montenegro, R. C., Militão, G. C., Fonseca, A. M., Pessoa, O. D., Lemos, T. L. & Costa-Lotufo, L. V. (2005). Bioactivity of biflorin, a typical o-naphthoquinone isolated from Capraria biflora L. *Journal of*

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

biosciences,, 60(5-6), 394–398. doi:https://doi.org/10.1515/znc-2005-5-605.

Visconti, F., & de Paz, J. M. (2016). Electrical conductivity measurements in agriculture: The assessment of soil salinity. *New trends and developments in metrology*, *1*, 99-126.

Vyas, S., Agoramoorthy, G., Gadhvi, K., Gamit, S., & Dangar, K. (2023). Correlation of elemental hyperaccumulation among the succulent and non-succulent halophytes of Gujarat. *India. Scientific Reports, 13*(1), 16361.

Walter, H. (1961). The adaptations of plants to saline soils. In: Arid Zone Research.XIV. Salinity Problems in the Arid Zones. *Proceedings of the Teheran* (pp. 129-134). Paris: UNESCO.

Wang, D., Yang, N., Zhang, C., He, W., Ye, G., Chen, J., & Wei, X. (2022). Transcriptome analysis reveals molecular mechanisms underlying salt tolerance in halophyte Sesuvium portulacastrum. *Frontiers in Plant Science*, *13*, 973419.

Wang, Y., Gao, M., Chen, H., Fu, X., Wang, L., & R, W. (2023). Soil moisture and salinity dynamics of drip irrigatin in saline-alkali soil of Yellow River basin. *Front. Environ. Sci., 11*(1130455). doi:10.3389/fenvs.2023.1130455

Water Science School. (2019, November 13). *How Much Water is There on Earth?* Retrieved from United States Geological Survey: https://www.usgs.gov /special-topics/water-science-school/science/how-much-water-there-earth

Weber, D. J. (2009). Adaptive mechanisms of halophytes in desert regions. In M. Ashraf, M. Ozturk, & H. Athar, *Salinity and Water Stress. Tasks for Vegetation Sciences* (Vol. 44, pp. 179-185). Dordrecht: Springer. doi:https://doi.org/10.1007/978-1-4020-9065-3_18

Wedekind, L. (2014, October 10). *Saline soils: Salt of the Earth*. Retrieved from IAEA: http://www.iaea.org/newscenter/features/ salinesoil/saline _part05 .shtml

Wiszniewska, A., Ko´zmi ´nska, A., Hanus-Fajerska, E., Dziurka, K., & Dziurka, M. (2021). Insight into phytochormonal modulation of defense mechanisms to salt excess in a halophyte and a glycophyte from Asteraceae family. *Plant Soil, 463*, 55–76.

Wu, P., Cogill, S., Qiu, Y., Li, Z., Zhou, M., & Hu, Q. (2020). Comparative transcriptome profilingprovides insights into plant salt tolerance in seashore paspalum (Paspalum vaginatum). *BMC Genomics*, 131. doi:10.1186/s12864-020-6508-1

Digitized by Sam Jonah Library

Wu, X., Shi, H., & Guo, Z. (2018). Overexpression of a NF-YC gene results in enhanced drought and salt tolerance in transgenic seashore paspalum. *Front. Plant Sci., 9*. doi:10.3389/fpls.2018.01355

Wungrampha, S., Rawat, N., Singla-Pareek, S.L., Pareek, A. (2021). Survival Strategies in Halophytes: Adaptation and Regulation. In: Grigore, MN. (eds) Handbook of Halophytes. Springer, Cham. https://doi.org/10.1007/978-3-030-57635-6_56

Yeo, A. R., & Flowers, T. J. (1986). Salinity resistance in rice (Oryza sativa L.) and a pyramiding approach to breeding varieties for saline soils. *Austr. J. Plant Physiol., 13*, 161–173. doi:10.1071/PP9860161

Yildirim, E., & Güvenç, İ. (2006). Salt tolerance of pepper cultivars during germination and seedling growth. *Turkish Journal of Agriculture and Forestry, 30*(5), 347-353.

Yousif, B. S., Nguyen, N. T., Fukuda, Y. A., Hakata, H., Okamoto, Y., Masaoka, Y., & Saneoka, H. (2010). Effect of salinity on growth, mineral composition, photosynthesis and water relations of two vegetable crops; New Zealand spinach (Tetragonia tetragonioides) and water spinach (Ipomoea aquatica). *International Journal of Agriculture and Biology, 12*(2), 211-216.

Youssef, A. M. (2009). Salt tolerance mechanisms in some halophytes from Saudi Arabia and Egypt. *Research Journal of Agriculture and Biological Sciences, 5*, 191-206.

Yuan, F., Leng, B. Y., & Wang, B. S. (2016). Progress in Studying Salt Secretion from the Salt Glands in Recretohalophytes: How Do Plants Secrete Salt? *Front. Plant Sci., 7*.

Zhang, Y., Ding, J., & Wang, H. (2020). Biochar addition alleviate the negative effects of drought and salinity stress on soybean productivity and water use effiency. *BMC Plant Biology, 20*, 288. doi:htts://doi.org/10.1186/s12870-020-02493-2

Zhao, K., Fan, H., Song, J., Sun, M., Wang, B., Zhang, S., & Ungar, I. (2005). Two Na+ and Cl? hyperaccumulators of the Chenopodiaceae. J. Integr. *Plant Biol., 47* (3), 311–318.

Zhao, K., Zhang, W., Fan, H., Song, J., & Jiang, X. (2001). Biological measures in amelioration and utilisation of saline soils. *Soil Bull., 32*, 115–119.

Zhou, G., Ma, B. L., Li, J., Feng, C., Lu, J., & Qin, P. (2010). Determining salinity threshold level for castor bean emergence and stand establishment. *Crop Sci., 50*, 2030–2036. doi:10.2135/cropsci2009.09.0535

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

Zou, T., Pu, L., Lin, R., Mo, H., Wang, Z., Jian, S., & Zhang, M. (2022). Roles of Canavalia rosea metallothioneins in metal tolerance and extreme environmental adaptation to tropical coral reefs. *Journal of Plant Physiology*, 153559. doi:doi.org/10.1016/j.jplph.2021.153559

Digitized by Sam Jonah Library

APPENDICES

Appendix 1: Analysis of variance for Relative Plant Height Growth Rate (RHGR) (Sample ANOVA Table for Experiment 1)

Variate: Plant height growth rate

Source of variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Plant	4	0.111698	0.027925	3272.007	6.39E-94
Soil	1	0.000378	0.000378	44.30019	2.41E-09
Salt	2	0.017565	0.008782	1029.064	2.82E-61
Rep	3	2.78E-05	9.25E-06	1.084176	0.360164
Plant * Soil	4	0.000343	8.57E-05	10.03929	9.97E-07
Plant * Salt	8	0.023471	0.002934	343.7705	2.11E-62
Soil * Salt	2	0.000109	5.47E-05	6.409365	0.002531
Plant * Soil * Salt	8	0.000349	4.37E-05	5.11802	3.08E-05
Residuals	87	0.000742	8.53E-06	NA	NA

Appendix 2: Analysis of variance for Shoot Dry Weight (SDW) (Sample ANOVA Table for experiment 2)

Variate: Shoot dry weight

Source of variation	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Salt	2	0.520703	0.260351	86.02708	1.35E-16
PD	3	2.769178	0.923059	305.0035	3.03E-31
Block	1	0.011756	0.011756	3.884351	0.054519
Salt * PD	6	0.476164	0.079361	26.22289	1.39E-13
PD * Block	3	0.005111	0.001704	0.562949	0.64208
Residuals	48	0.145267	0.003026	NA	NA

Digitized by Sam Jonah Library

Appendix 3: Gravimetric Field Capacity Determination

The determination of field capacity for both sea sand and arable soil (UCC) was carried out using the following parameters:

i. Percentage (%) moisture content at field capacity
ii. Percentage (%) moisture content of air-dry soil
iii. Weight of oven dry soil in nursery bags
iv. Amount of water in each nursery bag at field capacity
v. Amount of water to add to each soil poly bag to reach field capacity

Percentage moisture at field capacity

Estimation was carried out using four (4) replications with the formula

Field capacity per centage moisture = $\frac{\text{Wt of wet soil} - \text{Wt of oven dried soil} \times 100}{\text{Weight of oven dried soil}}$

The mean of the three replicates was used to estimate the field capacity

Per centage moisture in air dried soil

Percentage moisture of air-dried soil = $\frac{\text{Wt of air} - \text{dried soil} - \text{Wt of oven dried soil} \times 100}{\text{Weight of oven dried soil}}$

Weight of oven dried soil in pot

Weight of oven dried soil to fill polybag = $\frac{\text{wt of air} - \text{dried soil to fill nursery bag} \times 100}{100 + \text{air} - \text{dried soil \% moisture}}$

Water content of nursery bags at field capacity

Amount of water that would be present in each bag at field capacity was also determined as,

Digitized by Sam Jonah Library

University of Cape Coast https://ir.ucc.edu.gh/xmlui

The weight of soil and water at field capacity =

$$\frac{[100 + \%\text{moisture at field capacity}] \times \text{Wt of oven}-\text{dried soil}}{100}$$

Water to add to each soil filled polybag to reach field capacity

Weight of water to add per polybag = Wt. of soil + Water at field capacity – Wt. of air-dried soil.

Water to add to each soil filled polybag to reach 60% field capacity

Weight of water to add per polybag = (Wt. of soil + Water at field capacity – Wt. of air-dried soil) × 0.6

Digitized by Sam Jonah Library