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Sustainable agriculture solution for saline soil and brackish water-based irrigation

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Sustainable agriculture solution for saline soil and brackish water-based irrigation

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Dedication

To my esteemed parents,

Whose unwavering care and support have been invaluable,

To my beloved wife and cherished children,

Whose unwavering belief in both me and my endeavors has been a constant source of strength,

To my esteemed circle of friends,

And to my revered educators,

I extend my heartfelt gratitude to each and every one of you.

Sincerely,

Sobhi Yaghi

Declaration

I Certify that this thesis submitted for the degree of Master of Science in environmental studies is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for higher degree to any other university or institution.

Sobhi Salah Sobhi Yaghi

Signature: ……………………… Sobhi Yaghi 2023

Date: 30/11/2023

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Abstract

Salinity is one of the most brutal environmental factors limiting the productivity of crop plants. High rates of evapotranspiration, excessive fertilizer use, and inadequate irrigation water quality are the key contributors to the salinization problem in Jordan Valley. On the other hand, the wastewater treatment plants could produce sludge that is a good source of plant nutrients such as nitrogen, phosphorus, and potassium.

One of the solutions is the use of Plant growth-promoting bacteria (PGPB) and plant growth-promoting rhizobacteria (PGPR) to utilize nutrients and modify them to be more soluble for plants in the soil to absorb that and usage. The purpose of this research is to study the effect of sludge and PGPR application on saline soil and examine the effect of irrigation with fresh and brackish water on the development of three selected crops: Wheat, Ponicam, and Corn.

For this study, twenty-four lines of pipes were distributed on 3 Dunums, where six trials/lines were used for separate treatment: control trials, PGPR trials, Sludge trials, and a mix between Sludge and PGPR trials. Each treatment contained three trials of wheat, corn, and ponicam, and was rinsed with fresh and brackish water in each trial separately.

The study was conducted at the Arab Development Society, where sludge samples were brought from the Jericho Wastewater Treatment Plant. The study spanned a duration of ninety days, during which measurements were taken from three distinct periods: 14, 30, and 90 days. Plant measurements were analyzed statistically using one-way ANOVA at $p < 0.05$.

Results revealed that applying all treatments had no significant mean difference at $p < 0.05$, where p value was greater than 0.05, for wheat and ponicam but show a significant value for corn, where p value was lower than 0.05, for each plant stem length and width, plant leaf number, plant leaf length, and width. Notably, control treatments exhibited lower measurements for all of parameters compared to the treated samples.

After being exposed to PGPR and sludge without fertigation, the plant's health and productivity was improved due to the available elements being supplied to the plant after the action of PGPR on the sludge. This enhancement was evidenced by an increased number of leaves, wider stems, and longer stems observed after a 90-day period. Salt ion measurements in plant tissues show higher sodium (Na^+) and chloride (Cl^-) concentrations in PGPR and sludge-treated crops compared to the control for corn, wheat, and ponicam.

The study recommends the use of PGPR and sludge with fresh water for corn irrigation and suggests further research on Plant Growth-Promoting Bacteria (PGPB) and sludge applications. In conclusion, coated seeds irrigated with brackish water exhibit efficiency in overcoming salinity stress, and the addition of sewage sludge partially alleviates the negative impact of salinity stress on plant growth.

حل زراعي مستدام للتربة المالحة والري القائم على المياه معتدلة الملوحة

إعداد: صبحي صلاح صبحي ياغي

إشراف: أ. د. جواد حسن شقير

الملخص

الملوحة هي واحدة من أكثر العوامل البيئية قسوةً التي تحد من إنتاجية نباتات المحاصيل. معدلات عالية من التبخر والنقل النباتي، واستخدام الأسمدة الزائدة، وجودة مياه الري غير المناسبة هي المساهمون الرئيسيون في مشكلة التملح في وادي الأردن. يمكن أن تنتج محطات معالجة مياه الصرف الصحي طينًا يعتبر مصدرًا جيدًا للعناصر الغذائية للنباتات مثل النيتروجين والفوسفور والبوتاسيوم. يمكن أن تستفيد بكتيريا تعزيز نمو النباتات (PGPB) وبكتيريا تعزيز نمو الجذر (PGPR) من هذه العناصر وتعديلها لتكون أكثر قابلية للذوبان للنباتات في التربة. هدف هذا البحث هو دراسة تأثير تطبيق الطين و PGPR على التربة المالحة وفحص تأثير الري بالماء العذب والمالح على تطوير ثلاث محاصيل مختارة: القمح والبونيكام والذرة.

لهذه الدراسة، تم توزيع أربع وعشرون خطًا من الأنابيب على 3 دونمات، حيث استخدمت ست تجارب/خطوط لكل معاملة منفصلة: تجارب المراقبة، وتجاربPGPR ، وتجارب الطين، ومزيج بين تجارب الطين و PGPR. كانت كل معاملة تحتوي على ثلاث تجارب للقمح والذرة والبونيكام، وكانت تُغسل بالماء العذب والمالح في كل تجربة على حدة. تمت الدراسة في جمعية التنمية العربية، حيث تم جلب عينات الطين من محطة معالجة مياه الصرف الصحي في أريحا. استمرت الدراسة لمدة تسعين يومًا، خلالها تم أخذ قياسات في ثلاث فترات متميزة: 14 و30 و90 يومًا. تم تحليل قياسات النبات إحصائيا باستخدام أناليز واي أن أو فيه واحد عند مستوى الدلالة $p < 0.05$. أظهرت هذه الدراسة أن تطبيق جميع المعاملات لم يكن له فارق معنوي في $p < 0.05$ بالنسبة للقمح والبونيكام ولكن كان هناك قيمة معنوية للذرة بالنسبة لطول وعرض ساق النبات وعدد وطول وعرض أوراق النبات. ولاحظ أن المعاملات التحكمية أظهرت قياسات أقل في جميع هذه المعايير مقارنة بالعينات المعالجة. بعد التعرض لـ PGPR والطين بدون التسميد، تحسنت صحة النبات وإنتاجيته. وقد تجلى هذا التحسن في زيادة عدد الأوراق وتوسع السيقان وزيادة طول السيقان بعد فترة قدرها 90 يومًا.

قياسات أيونات الملح في أنسجة النبات تظهر تراكيزًا أعلى لأيونات الصوديوم (Na^+) والكلور (Cl^-) في المحاصيل التي تمت معالجتها بـ PGPR والطين مقارنة بالسيطرة للذرة والقمح والبونيكام. توصي الدراسة باستخدام PGPR والطين مع الماء العذب لري الذرة وتقترح إجراء بحوث إضافية حول تطبيق بكتيريا تعزيز نمو النباتات (PGPB) والطين. وفي الختام، تظهر البذور المغلفة والتي تروى بالماء المالح فعالية في التغلب على ظروف التوتر الملحي وإنتاج كميات أكبر من الكتلة الحيوية مقارنة بالبذور غير المعالجة، وإضافة الطين الصحي جزئيًا تخفف الأثر السلبي للتوتر الملحي على نمو النبات.

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List of Abbreviations

SOC	Soil Organic Carbon
CEC	Cation Exchange Capacity
PGPB	plant growth promoting bacteria
PGPR	plant growth promoting rhizobacteria
N	Nitrogen
P	Phosphorus
K	Potassium
ADS	Arab Development Society
K^+	Potassium Icon
Na^+	Sodium Ion
Mg^{+2}	Magnesium Ion
Ca^{+2}	Calcium Ion
Cl^-	Chloride Ion
HCO_3^-	Bicarbonate
NO_3^-	Nitrate
SO_4^{-2}	Sulfur oxide or Sulfate
CO_3^{-2}	Carbonate Ion
CNF	Control Corn - Fresh Water
CNB	Control Corn - Brackish Water
PNF	PGPR trials Corn - Fresh water
PNB	PGPR trials Corn - Brackish water
SNF	Sludge Trials - Fresh Water
SNB	Sludge Trials - Brackish Water
S+PNF	Sludge Trials + PGPR trials Corn - Fresh Water
S+PNB	Sludge Trials + PGPR trials Corn - Brackish Water
B	Brackish Water
F	Fresh Water
C	Control Trials
S	Sludge Trials
P	PGPR Trials
W	Wheat
N	Corn
K	Ponicam
SPWF	Sludge PGPR Wheat Fresh Water
SWF	Sludge Wheat Fresh water
SWB	Sludge Wheat Brackish Water
CWF	Control Wheat Fresh Water
CWB	Control Wheat Brackish Water
PWF	PGPR Wheat Fresh water
PWB	PGPR Wheat Brackish Water
SPWB	Sludge PGPR Wheat Brackish Water
S+PKF	Sludge PGPR Ponicam Fresh Water
SKF	Sludge Ponicam Fresh water
SKB	Sludge Ponicam Brackish Water
CKF	Control Ponicam Fresh Water
CKB	Control Ponicam Brackish Water
PKF	PGPR Ponicam Fresh water
PKB	PGPR Ponicam Brackish Water
S+PKB	Sludge PGPR Ponicam Brackish Water

Chapter One

1.1 Introduction

Due to the detrimental consequences that salinity in soil can have on agricultural productivity and sustainability, salinity has emerged as a significant issue on a global scale (Zaman et al., 2018). More than one hundred countries have soils that have been negatively impacted by salt, and irrigation is typically one of the primary contributors (Tnay, 2019). As a result, the need to increase the size of cultivated land drives the expansion of agricultural activities into marginal areas, which frequently face salinity problems (Maja & Ayano, 2021; Qadir & Oster, 2004). Freshwater resources were and still are limited (Feitelson, 2002), and they were not sufficient to support the day-to-day demands of humans (Feitelson et al., 2012). As a result of these studies and in order to increase agricultural output and make use of alternative water resources, there is a demand for an appropriate solution, and this demand should be matched with approaches that are environmentally benign and sustainable.

Table (1.1): Classification of salt-affected soils (A. J. S. U. Singh & Management, 2022)

Soil Type / Soil Properties	**EC (dS/m)**	**pH**
Saline Soil	>4	<8.5
Alkaline Soil	<4	>8.5
Saline-Alkaline Soil	>4	>8.5

One of the most significant obstacles confronting the agricultural sector at present is the high salinity of the soil (Machado & Serralheiro, 2017), and this is especially true in the Jordan Valley, which is the most significant agricultural region in Palestine. High rates of evapotranspiration, excessive fertilizer use, and inadequate irrigation water quality are the key contributors to the salinization problem in Jordan Valley (Ammari et al., 2013).

The possibility of using sewage sludge, a byproduct of municipal wastewater treatment processes, as a soil amendment to alleviate the salinity stress of saline soils is highly attractive (Nunes et al., 2021). Sewage sludge is rich in organic compounds and plant nutrients, and it can be considered as a valuable source of N, P, and K which are essential plant nutrients (Kominko et al., 2019). Accordingly, the reuse of sludge may substitute substantially part of the needed plant nutrients. However, there is a need for ecotoxicological evaluation of the usage of sludge. It is well known that urban sludge is usually non-toxic, whereas sludge from industrial zones might be very toxic.

According to Sanchez et al. (2019), sludge has the potential to be an abundant source of microorganisms known as PGPB, where bacteria are the most common and ecologically significant microorganisms found in soil, and it also has the potential to include PGPR. There have been reports of multiple species of PGPB being able to fix nitrogen and boost soil fertility, as well as solubilize phosphate, stimulate the cleaning of heavy metals, and enhance the performance of crops while they are under stress from drought and salinity (Majeed et al., 2018).

1.2 Problem Statement

Salinization of soils in Palestine, in particular in the Jericho district, is a serious problem facing protected agriculture, mainly due to the excessive use of chemical fertilizers and the inferior quality of irrigation water, where when fertilizers are applied in excess of what the plants can absorb, the unused salts can accumulate in the soil over time. This accumulation of salts, including sodium and chloride ions, leads to soil salinization. The salts can negatively impact plant growth by disrupting water and nutrient uptake.

1.3 Study Justification

Wastewater treatment plant sludge is a good source of the plant nutrients nitrogen (N), phosphorus (P), and potassium (K). As a result, sludge can be reused to provide plants with some of the nutrients they need. PGPB and PGPR could fix nitrogen from air and sludge to soil, to enhance its fertility and reduce salinity.

1.4 Study Goals

The purpose of this research is to examine how adding sludge to saline soil (Dudeen et al., 2001) affects the development of the three selected crops (Wheat, Ponicam, and Corn) and how effective PGPR is at supporting plant growth in adverse conditions.

The Specific Objectives are:

1) To study the synergistic effect of PGPR in promoting plant growth under salinity conditions.
2) To find the best solution for reducing soil salinity by reusing sludge in a proper mixing ratio that meets two criteria: accepted salinity rate and accepted health specifications.
3) Reducing soil salinity in the lands in the agricultural field.

1.5 Study Location

Sludge samples were taken from the Jericho Wastewater Treatment Plant, while the study application was done in the Arab Development Society – Jericho on three dunums (Figure 1.1). The climate was warm to cold in Jordan Valley in the period of autumn-winter.

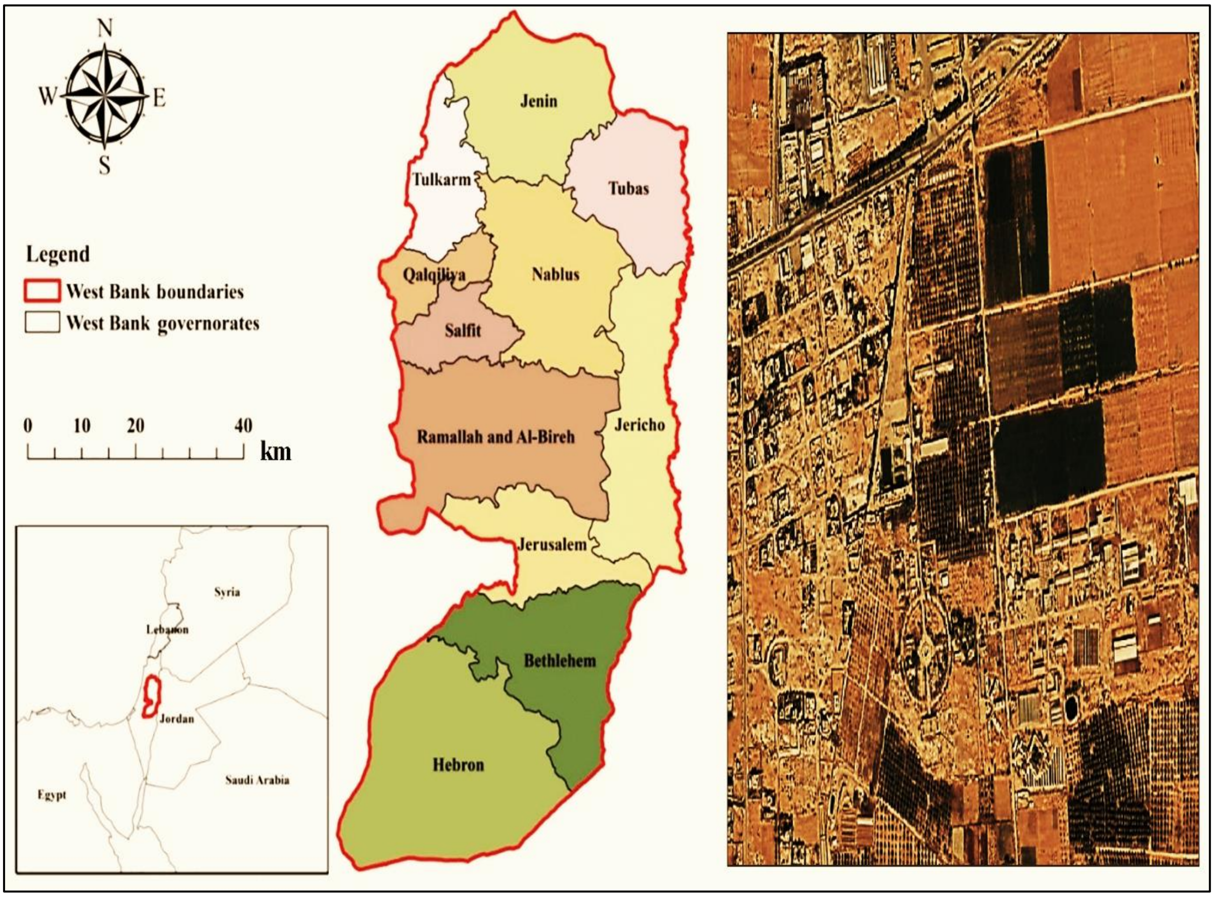


Figure (1.1): Modified map for West Bank and ADS. West Bank map was supported by (Shadeed et al., 2019) where ADS Map was taken through Google Earth (2023)

1.6 Study Questions

- What is the effect of PGPR on plant germination and production in saline soils?
- What is the effect of sludge amendment on soil salinity?

Chapter Two: Literature Review & Previous Studies

2.1 Literature Review

2.1.1 Soil Salinity

Salinity is one of the most brutal environmental factors limiting the productivity of crop plants because most of crop plants are sensitive to salinity caused by high concentrations of salts in the soil (Shrivastava & Kumar, 2015). Saline soil is defined as soil that contains high amounts of cations, especially sodium. (Horneck et al., 2007) Soil salinity refers to the presence of major dissolved inorganic solutes in the soil aqueous phase, which consist of soluble and readily dissolvable salts including charged species (e.g., Na^+, K^+, Mg^{+2}, Ca^{+2}, Cl^-, $HCO3^-$, $NO3^-$, $SO4^{-2}$ and $CO3^{-2}$) (Corwin & Lesch, 2005), these ions directly influence the electrical condition, which is considered as the most reliable measurement of salinity level (Adviento-Borbe et al., 2006).

Salinity has a negative impact on plant growth and development. (Safdar et al., 2019) Soil salinity produced by natural or human activities is considered a major environmental hazard (Metternicht & Zinck, 2003). The natural factors include weathering of minerals from rocks that contain a naturally large proportion of salts (Fookes et al., 1988; Rodriguez-Navarro & Doehne, 1999). Water accumulates in low places leading to poor drainage and low permeability soil water (Okur & Örçen, 2020), and high evaporation rates lead to the accumulation of salts on the surface of the soil (Fujimaki et al., 2006). As for anthropogenic factors, the interaction of humans with the environment represents the major factors affecting the degree of salinity of soils (Peters & Meybeck, 2000) such as the addition of excessive chemical fertilizers to agricultural land and greenhouses (Savci, 2012).

Soil salinity constitutes a serious problem for crop production as salinity suppresses plant growth (Upadhyay et al., 2012). Previous studies suggest that utilization of PGPB has become a promising alternative to alleviate plant stress caused by salinity (Yao et al., 2010) and the role of microbes in the management of biotic and abiotic stresses is gaining importance. The subject of PGPR tolerance to abiotic stresses has been reviewed recently. (Dodd & Perez-Alfocea, 2012)

2.1.2 Brackish Water in Jordan Valley

Palestinians in the West Bank and the Gaza Strip are suffering from water shortages because of Israeli restrictions on access to and use of the available water resources (Taha & Al-Sa'ed, 2018). Groundwater is the only source of water in the West Bank. In 2002, the annual supply was about 130 million cubic meters, and 75% of this volume originated from groundwater wells and springs while the rest (25%) was purchased from the Israeli company "Mekerot" (Fisher et al., 2002). Water demand increasing with the increase of population where Palestinian population has risen by 38.2% during the past 20 years and the water supply is still unsatisfactory. The increasing salinity of the groundwater is one of the major challenges faced by the agricultural sector in West Bank/Palestine (Marei et al., 2014).

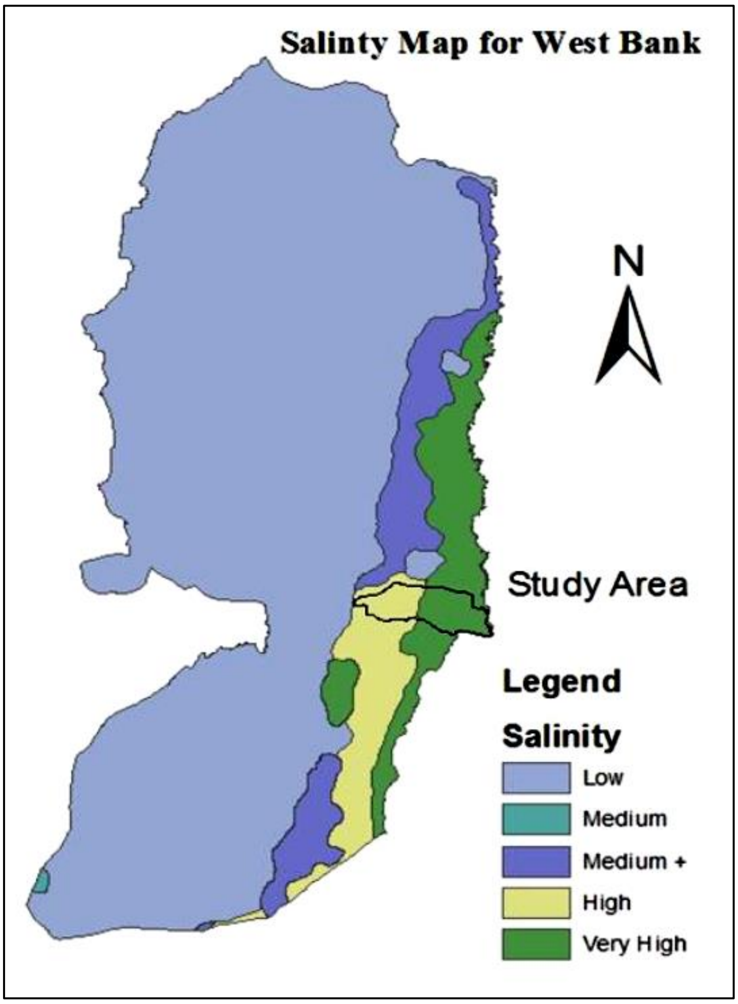


Figure 2.1: Water Salinity map of West bank. (PWA, 2012)

2.1.3 Sewage Sludge Benefits

Sewage sludge, also referred to as biosolids, is a byproduct of sewage treatment processes (R. Singh & Agrawal, 2008). Sewage sludge consists of a heterogeneous mixture of useful and harmful compounds, organic matter, and macro and microelements (Lasaridi et al., 2018). Application of municipal sewage sludge in agriculture is one of the best options for its safe disposal as it provides an opportunity to recycle plant essential nutrients (Huang & Yuan, 2016; Kirchmann et al., 2017) such as nitrogen and phosphorous (Cieślik & Konieczka, 2017; Saha et al., 2017).

2.1.4 Plant growth promoting Rhizobacteria

Plant growth-promoting rhizobia (PGPR) is a group of microorganisms that have distinct capabilities to assist the plant root systems (V. Kumar et al., 2022) in terms of efficient survival and nutrient deliverability (Nascimento et al., 2018). Plant growth-promoting rhizobacteria (PGPR) is considered an innovative, effective, and eco-friendly approach (Javed et al., 2020). Commercial-scale PGPRs commonly known as biofertilizers have shown substantial improvements in plant growth and crop yields, making agriculture more profitable (R. Kumar et al., 2020). A new sustainable method has been implemented as a trial which is focused on coating seeds with certain PGPR strains (Backer et al., 2018), where these bacteria could enhance plants to grow under saline conditions (Mahmood et al., 2016).

The beneficial microbial-plant interaction plays a significant role in soil health, crop growth, and productivity (Panwar et al., 2016). Several strategies have been developed in order to decrease the toxic effects caused by high salinity on plant growth (Wang et al., 2003) and recently the use of plant growth-promoting bacteria (PGPB) (Dimkpa et al., 2009). The role of microorganisms in plant growth promotion, nutrient management, and disease control is well known and well established. These beneficial microorganisms colonize the rhizosphere/endo-rhizosphere of plants and promote the growth of the plants through various direct and indirect mechanisms (Nia et al., 2012; Ramadoss et al., 2013).

2.2 Previous Studies

Vaca et al. (2011) studied the ability of organic wastes to improve soil productivity, physical, and chemical properties. Where sewage sludge, compost, and inorganic fertilizer were applied to soil and corn grains (*Zea mays L*) to determine their effects on nickel, copper, zinc, corn productivity, and grain nutritional quality. Sewage sludge and compost at 18 $\mathrm{Mg.ha^{-1}}$ and mineral fertilizer (N-P-K) at 150-75-30 were applied. Sewage sludge-, compost-, and inorganic fertilizer soils differed in organic matter, phosphorus, and zinc ($P < 0.05$). Compost soil has a high copper concentration ($P < 0.05$). Compost-soil and sewage sludge-soil mixes produced more than inorganic fertilizer soil. Starch, total nitrogen, protein, acid detergent fiber, and neutral detergent fiber percentages were sufficient for human consumption. Sewage sludge or compost did not raise grain heavy metal concentrations compared to inorganic fertilizer soil.

Hamed (2014) isolated two strains of PGPR from natural substances and used them with barley (*Hordeum valgare* L.) and malt (*Panicum maximum Jacq*.). His study showed that plants treated with PGPRs and irrigated with brackish water increased significantly in biomass percentage for trails treated with fresh ware, 6000 mg/L, and 10000 mg/L of brackish water-related for Treated Barley seeds with UW3 (237.31%, 249.40%, 156.11%) and UW4 (156.11%, 237.31%, 288.83%) and for trials treated with UW3 and UW4 (128.12%, 267.67%, 288.56%) compared to control trials with fresh PGPR-treated roots and shoots were 283% longer (respectively). Salt ions were higher in shoots/0.114m^2. Decant water TDS was 0.101 mg/L. Electrolyte leakage assay showed that plants treated with PGPRs had the same values as freshwater trials and decreased membrane electrolyte leakage of 304 mg/L. PAM fluorometry parameters Fv/Fm, Y (II), and QN showed that PGPRs boosted brackish water photosynthesis.

Chang et al. (2014) studied Plant growth-promoting bacteria (PGPB) strains that contain the enzyme 1-amino- cyclopropane-1-carboxylate (ACC) deaminase can lower stress ethylene levels and improve plant growth. In this study, ACC deaminase-producing bacteria were isolated from a salt-impacted (~50 dS/m) farm field, and their ability to promote plant growth of barley and oats in saline soil was investigated in pouch assays (1% NaCl), greenhouse trials (9.4 dS/m), and field trials (6–24 dS/m). A mix of previously isolated PGPB strains UW3 (Pseudomonas sp.) and UW4 (P. sp.) was also tested for comparison. Rhizobacterial isolate CMH3 (P. corrugata) and UW3+UW4 partially alleviated plant salt stress in growth pouch assays. In greenhouse trials, CMH3 enhanced root biomass of barley and oats by 200% and 50%, respectively. UW3+UW4, CMH3 and isolate CMH2 also enhanced barley and oat shoot growth by 100%–150%. In field tests, shoot biomass of oats tripled when treated with UW3+UW4 and doubled with CHM3 compared with that of untreated plants. PGPB treatment did not affect salt uptake on a per mass basis; higher plant biomass led to greater salt uptake, resulting in decreased soil salinity. This study demonstrates a method for improving plant growth in marginal saline soils. Associated implications for salt remediation are discussed.

Uzinger et al. (2020) studied the impact of sewage sludge Compost and Bacterial Inoculum on Acidic Sandy Soil in a pot experiment, sewage sludge compost (up to 0.5%), biochar made of paper sludge and grain husk (BC) (up to 2%) and plant growth-promoting rhizobacterial (PGPR) inoculum were tested for their short-term effects on acidic sandy soil at 65% field capacity. Two-month trials examined soil pH, organic matter, total and plant-available nutrients, substrate-induced respiration, AMF root colonization parameters, and corn (Zea mays L.) biomass. After combining the application, BC's positive priming (21% organic matter loss) disappeared. Due to increased microbial activity, compost and PGPR with 1.5% BC increased P and K availability by 35%. Only 0.5% compost increased corn biomass 2.7 times. Combinations had the highest microbial activity and lowest AMF colonization. BC, compost, and PGPR did not increase soil fertility in the short term. For better understanding, further combined treatments on acidic sandy soil are needed.

Tang et al. (2022) investigated the feasibility of producing high-quality liquid fertilizer with N-PGPN and N-PGPB recovery through alkaline thermal hydrolysis (ATH) using $Ca(OH)2$. Results suggested that ATH treatment was superior in N solubilization (TSN/TN > 54%) and organic N maintenance in sludge liquor (> 80%) when compared to single thermal hydrolysis (TH). More surprisingly, ATH also promoted the production of N-PGPN and N-PGPB. As for N-PGPN, the maximum free amino acids (FAAs) accumulation in ATH liquor was 56.82 g/L at 120 °C while soluble protein (SPN) and soluble humic acid (SHA) reached 8.30–8.88 g/L and 1.88–2.05 g/L at 140–160 °C. The greatest N-PGPB produced by ATH treatment was achieved at 160 °C, with the detection of 1.156 mg/L phytohormones (indole-3-acetic acid and hydroxyphenyl acetic acids) and 4.95 mg/L allelochemicals (indolic derivatives and aromatic carboxylic acids). The 2D correlation FTIR maps analyses suggested, compared with TH, ATH could achieve protein hydrolysis before polysaccharides solubilization and denaturation with the temperature increased, thus avoiding Maillard reaction and benefiting N-PGPB production. Moreover, the laboratory investigation and field study indicated the usage of ATH liquor improved the growth of plants without inducing heavy metal contamination and soil salinization. Hence, ATH is a promising technology to produce high-quality liquid fertilizer rich with N-PGPN and N-PGPB from sewage sludge, especially suitable for such sludge with a low VS/TS ratio where biological treatment is inapplicable.

Chapter Three: Methodology

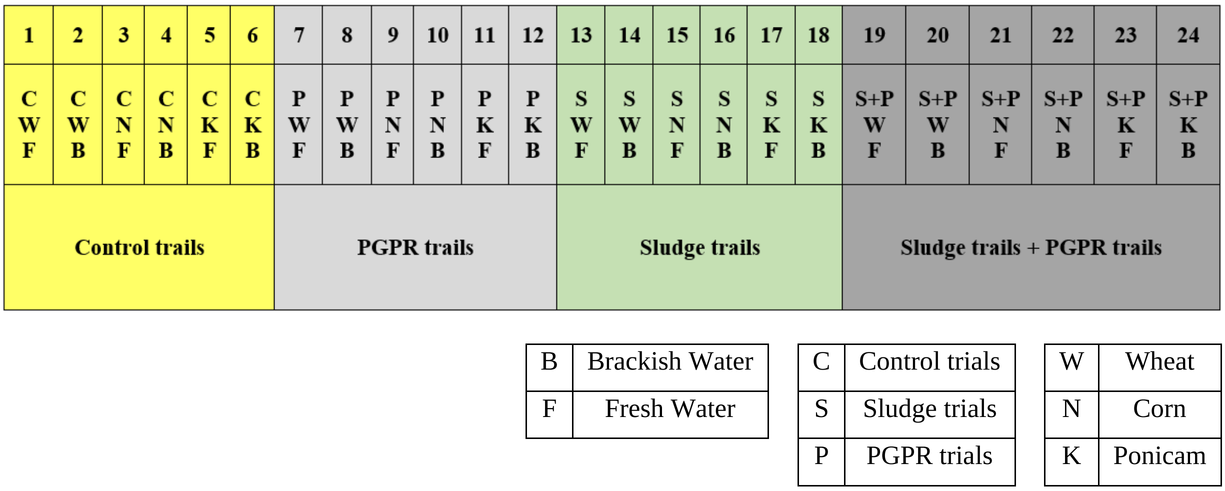
3.1 Materials and Tools

This study utilized a wide range of lab resources, such as meters for measuring pH and EC, soil bags, sample cups, an EQUS autoclave, a weighing balance, a water distiller, beakers and flasks of varying sizes, glass rods, a Buchner funnel, a vacuum air pump, polyethylene pipes, and a laminar flow hood.

3.2 Land Preparation

Polyethylene Pipes with a length of sixty meters and a diameter of fifty millimeters were rolled out to pump brackish water, and a water controller valve was installed at a distance of two inches between each pipe to regulate the amount of water that is used for irrigation. In addition, a tank of fresh water was installed and connected to pipes used for irrigation. The distance that separates each sample was forty centimeters, and the distance that separates each line was seventy centimeters.

Wheat, corn, and ponicam were cultivated, and there was a total of six hundred seeds. The number of cultivated plants grown on each freshwater and brackish water route has been fifty plants. The land includes three dunums categorized according to the following system:



1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
C W F	**C W B**	**C N F**	**C N B**	**C K F**	**C K B**	**P W F**	**P W B**	**P N F**	**P N B**	**P K F**	**P K B**	**S W F**	**S W B**	**S N F**	**S N B**	**S K F**	**S K B**	**S+P W F**	**S+P W B**	**S+P N F**	**S+P N B**	**S+P K F**	**S+P K B**
Control trails						**PGPR trails**						**Sludge trails**						**Sludge trails + PGPR trails**					

B	Brackish Water
F	Fresh Water

C	Control trials
S	Sludge trials
P	PGPR trials

W	Wheat
N	Corn
K	Ponicam

Figure (3.1): For crops and trails distribution, twenty-four lines of pipes are distributed on 3 Dunums.

3.2.1 Experiment Installation and Application

The area of three dunums of land has been divided into a few unique categories, and each of these categories corresponds to a distinct phase in the process of planting and harvesting crops. (See Figure 3.2). Pipes measuring sixty meters in length and fifty millimeters in diameter were rolled out with the intention of pumping brackish water through them. A controller valve, with dimensions of two inches by two inches and a distance of two inches, was positioned between each pipe at a distance of two inches so that the amount of water that is used for irrigation could be controlled. In addition to this, a water storage tank that was designed to be used for drinking was constructed, and pipes for irrigation were put in place. It was determined that there should be a space of forty centimeters between each sample and each line, and there should be a distance of seventy centimeters between each sample and each sample. Along each and every walkway that led to either the brackish water or the freshwater sections, a total of fifty plants were planted in their entirety. The planting was done with a total of six hundred seeds, which included several varieties of wheat, corn, and ponicam. The seeds were planted in the ground. All data were gathered from samples and analyzed in the lab (See Figure 3.3).

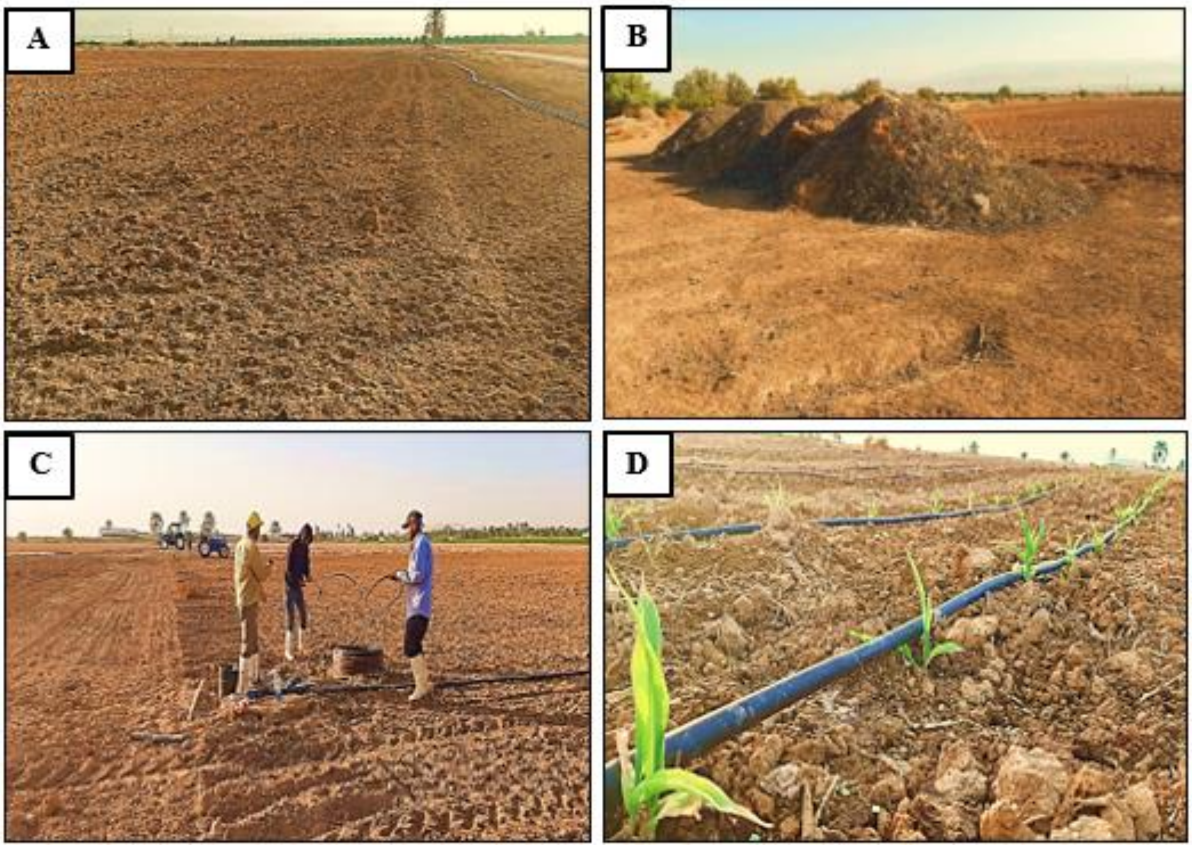


Figure (3.2): Experiments application in the field. (A) Land Tillage, (B) Sludge Installation, (C) Pipes Installation, (D) Plant growth, (E) Plant Measuring, (F) Whole Grown Plant.

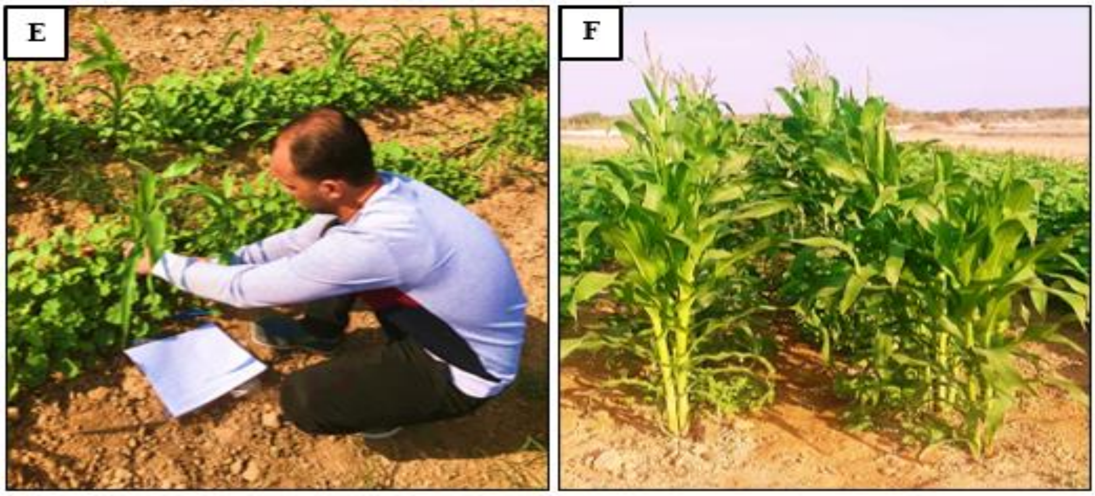


Figure (3.3) Continuo: Experiments application in the field. (A) Land Tillage, (B) Sludge Installation, (C) Pipes Installation, (D) Plant growth, (E) Plant Measuring, (F) Whole Grown Plant.

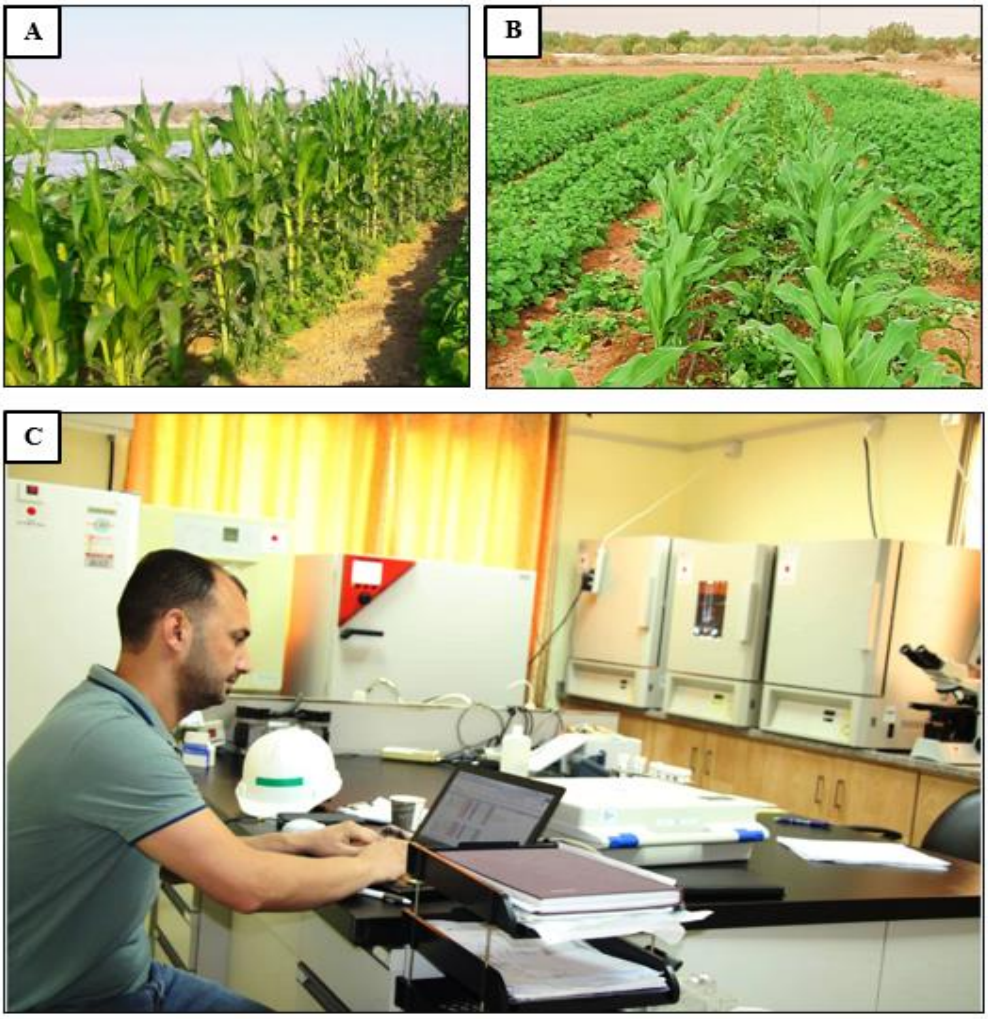


Figure (3.4): Data Gathering and Analysis. (A) Corn Plant, (B) Grown Plant height measurement, (C) Data Analysis.

3.2.2 Seed Treatment with PGPR

Seed treatment with PGPR was prepared based on the study of Hamed (2014) by coating seeds with PGPR, where control samples were not coated.

3.3 Soil and Sewage Sludge Sampling

In accordance with the diagram in Figure (3.5), soil samples were taken randomly from three dunums at the Arab Development Society. These dunums were part of the study. While sewage sludge samples were taken from the "Jericho Wastewater Treatment Plant" after finishing processing in accordance with the standard operating procedure, as they were precipitated as a first step of processing. On the other hand, soil that was high in salt (salty or Saline Soil) was obtained from a farm that is part of the Arab Development Society, where the coordinates of each sample are shown in Table 3.1.

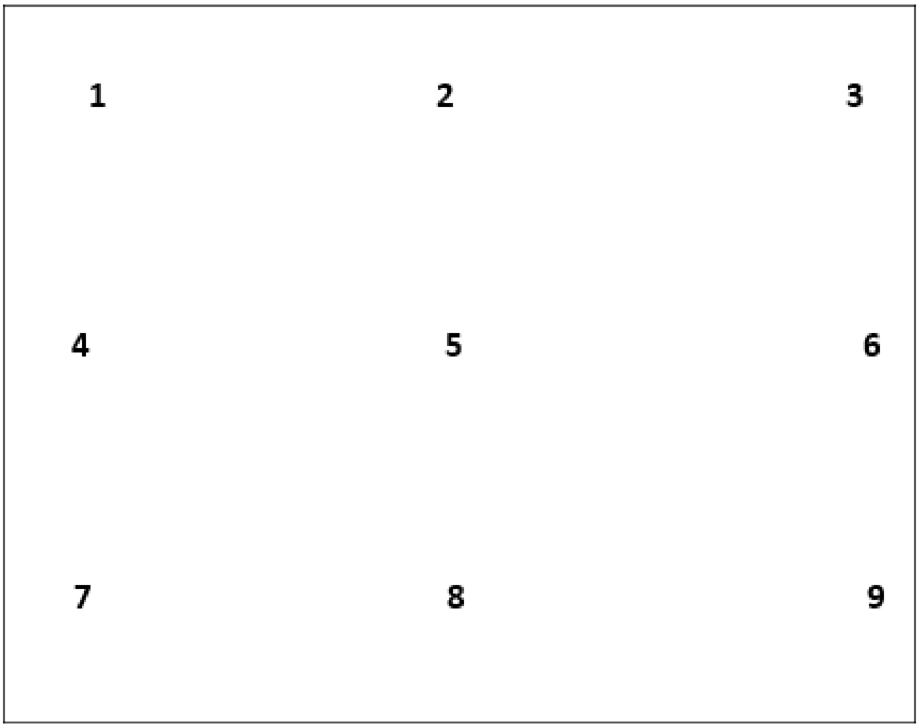


Figure (3.5): Soil samples selection map from 3 Dunums

Table (3.1): Saline soil samples numbers and locations

#	***Soil samples Number***	***Coordination***
1	First Sample	*North 0736496* *East 3528087*
2	Second Sample	*North 0736493* *East 3528104*
3	Third Sample	*North 0736494* *East 3528117*

4	Fourth Sample	*North 0736509* *East 3528094*
5	Fifth sample	*North 0736510* *East 3528103*
6	Sixth sample	*North 0736503* *East 3528119*
7	Seventh sample	*North 0736527* *East 3528692*
8	Eighth sample	*North 0736525* *East 3528107*
9	*Ninth sample*	*North 0736524* *East 3528120*

3.4 Samples Analysis

Five grams of air-dried soil with a particle size of less than 2 millimeters were weighed and added to a flask with a capacity of 250 milliliters. Forty-five milliliters of distilled water were added to the same flask, and the contents were thoroughly combined using a glass rod. After letting the solution sit undisturbed for half an hour, the suspension was stirred for an additional hour before being filtered through filter paper utilizing a Buchner funnel. The extracted solution was then utilized to determine the electrical conductivity utilizing a pH and EC meter. On the other hand, samples of sludge were collected from the Jericho municipality site treatment facility and transported to an analysis lab for examination.

Fresh water samples were taken from Ein Sultan and brackish water samples were taken from two ground wells: Zaytoon Groundwater Well Number 1 and Makateb Groundwater Well Number 2 and were analyzed for electrical conductivity and total dissolved solids.

3.5 Dry Biomass Calculation

Dry biomass determination for root and shoot from plant samples was done according to the procedures used by Hamed (2014) after 14, 30, and 90 days.

3.6 Statistical Analysis of Plant Measurements

Statistically significant differences between the mean values were evaluated by one-way analysis of variance (ANOVA) at ($p < 0.05$) using Minitab software (version 19).

Chapter Four: Results & Discussion

4.1 Main Results

Germinated corn demonstrated its maximum growth, salt accumulation, and biomass measurement between October 2020 and January 2021 for each treatment. Due to the salinity of the soil, it was impossible to make any valid comparisons between germinated corn that had been watered with brackish water and those that had been irrigated with fresh water. However, the corn that served as a control did not thrive.

The same was true for ponicam; measurements for each treatment were taken between October 2020 and January 2021, and the germinated crops displayed their maximum growth, salt accumulation, and biomass measurement during this period. There was no reliable way to measure how differently germinating ponicam responded to being irrigated with brackish water as opposed to fresh water because the soil was salty and there was no means to measure how differently the soil behaved. The color of the germinated treatments was green while the color of the control was yellowish, and this is an indication of saline stress even for the treatments with varied irrigation. For wheat, there was no significant comparison in lengths measuring between the germinated and the control.

The output from the previous studies and this study showcasing the potential benefits of plant growth-promoting bacteria, sewage sludge, and innovative technologies in enhancing soil fertility, plant growth, and nutrient recovery. All topics emphasize the importance of addressing soil salinity and exploring sustainable approaches for agriculture.

4.2 Samples Analysis

Several tests were done on the pH, electrical conductivity, and total dissolved solids of soil and water samples taken. The tests were carried out on both the soil and the water. Table 4.1 presents an overview of the findings obtained from the samples. The electrical conductivity (EC) of the different soil samples ranged from 10,300 to 18,870 S/cm. On the other hand, the total dissolved solids (TDS) of the soil samples, before culturing the plants, ranged anywhere from 5,210 to 9,560 mg/L. The pH of the soil fluctuated from 8.54 and 8.91 at various points. In spite of the fact that samples were collected from a wide array of groundwater wells, there was no detectable shift in the characteristics of the water. This was the case even though sludge has a pH value that is slightly on the acidic side and has characteristics that are slightly brackish. The majority of the samples had a pH value that was slightly more alkaline, and the salt levels that they had were brackish.

Table (4.1): Different Samples chemical analysis

Samples	*pH*	*EC (µS/cm)*	*TDS (mg/L)*
Soil one	8.72	10,300	5,210
Soil two	8.65	16,960	8,500
Soil three	8.54	15,820	8,020
Soil four	8.70	18,630	9,530
Soil five	8.63	10,350	5,520
Soil six	8.73	17,420	8,840
Soil seven	8.72	18,870	9,560
Soil eight	8.74	12,680	6,450
Soil nine	8.91	15,920	8,050
Water one	7.66	5,610	3,590
Water two	7.24	5,740	3,673
Sludge	6.76	3,800	1,650

4.3 Measurements of dry biomass of all treatments

In order to calculate the total amount of dry biomass contained within the plant, samples of the plant's roots and shoots were collected at 14, 30, and 90 days after the plants were first germinated. It was found that the total quantity of dry weight increased across the board, including in both the roots and the shoots that were included in the samples.

The treatment that consisted of PGPR and Sludge (P+S) corn and fresh water had the maximum dry weight for the plant shoot on the fourteenth day of the shoot experiments. Other top treatments included P+S wheat Fresh Water, PGPR corn Fresh Water, PGPR corn Brackish Water, P+S corn Brackish Water, and P+S Ponicam Fresh Water. All of these treatments generated a shoot with a greater dry weight than the control. All of these treatments consisted of administering pure water to the plants. Control - The Ponicam Brackish Water location has the lowest total amount of dry matter of any of the shoot's locations. When shoot samples were taken on day 30 and day 90, similar treatments produced a greater amount of dry biomass from the shoots at rates that were equal. The samples were gathered from the shoots.

It was found that the samples that had the highest dry weight of the root (PGPR trials and sludge trials or P+S corn Fresh Water) also had the highest dry weight of the shoot as described in Table 4.2. This suggests that the application of rhizobacteria, which stimulates plant growth, at the same time and site as sludge resulted in an increase in fresh weight that reflected on dry weight increase on the root and shoot of the plants as well.

Table (4.2): Dry weight of root and shoot of the plant samples.

#	**Biomass**	***Average Dry weight of shoot mg/Plant***			***Average dry weight of root mg/Plant***		
		14 days	**30 days**	**90 days**	**14 days**	**30 days**	**90 days**
1.1A	Control wheat Fresh Water	4.86	7.29	12.17	3.96	5.94	9.91
1.1B	Control wheat Brackish Water	4.23	6.34	10.56	3.65	5.47	9.12
1.2 A	PGPR Wheat Fresh Water	5.12	7.65	12.80	4.80	7.20	12.02
1.2 B	PGPR Wheat Brackish Water	5.01	7.51	12.33	4.75	7.12	11.87
1.3 A	Sludge Wheat Fresh Water	5.10	7.65	12.74	4.70	7.15	11.93
1.3 B	Sludge Wheat Brackish Water	4.90	7.35	12.25	4.35	6.52	10.88
1.4 A	P+S wheat Fresh Water	6.24	9.36	15.63	5.74	8.61	14.35
1.4 B	P+S wheat Brackish Water	5.25	7.87	13.08	5.10	7.63	12.60
2.1 A	Control corn Fresh Water	-	-	-	-	-	-
2.1 B	Control corn Brackish Water	-	-	-	-	-	-
2.2 A	PGPR corn Fresh Water	6.55	9.85	16.40	6.05	9.08	15.13
2.2 B	PGPR corn Brackish Water	6.20	9.15	15.10	5.96	8.80	14.83
2.3 A	Sludge corn Fresh Water	-	-	-	-	-	-
2.3 B	Sludge corn Brackish Water	-	-	-	-	-	-
2.4 A	P+S corn Fresh Water	7.31	10.9	18.27	6.22	9.33	15.55
2.4 B	P+S corn Brackish Water	7.01	10.05	17.35	6.10	9.02	14.95
3.1 A	Control Ponicam Fresh Water	3.55	5.33	8.9	3.85	5.78	9.63
3.1 B	Control Ponicam Brackish Water	3.05	4.52	7.59	3.0	4.41	7.50
3.2 A	PGPR Ponicam Fresh Water	5.12	7.70	12.80	4.45	6.71	11.10
3.2 B	PGPR Ponicam Brackish Water	4.85	6.95	10.10	3.95	6.00	10.05
3.3 A	Sludge Ponicam Fresh Water	4.95	7.43	12.38	4.10	6.15	9.50
3.3 B	Sludge Ponicam Brackish Water	4.90	7.25	12.12	3.85	5.70	9.10
3.4 A	P+S Ponicam Fresh Water	6.15	9.24	15.38	5.95	9.10	14.88
3.4 B	P+S Ponicam Brackish Water	5.85	8.79	14.65	5.45	8.18	13.64

4.4 Measurements of salt (Na^+ & Cl^-) ions (mg/g dry weight) in Plants tissue

The presence of salt ions (sodium and chloride) in the tissues of plants was investigated. It was found that the concentration of these ions was greater in corn germinated with PGPR and Sludge than it was in control wheat (Table 4.3), which had the lowest type of concentration. According to these findings, the accumulations of Cl^- ions and Na^+ ions in plant tissue were unequal, with Na^+ accumulations being higher than Cl^- accumulations. This leads one to hypothesize that plants make greater use of Cl^- for their biosynthesis. It also shows that the PGPR has a role in increasing the salt accumulation inside plant leaves.

Table (4.3): Measurements of Sodium and Chloride in Plant tissues

#	***Treatment With brackish water***	***Na (mg/g dryweight)***	***Cl (mg/g dry weight)***
2	Control wheat	0.866	0.765
3	Germinated wheat P+S	2.878	1.864
4	Control corn	-	-
5	Germinated Corn P+S	9.686	7.675
6	Control Ponicam	2.142	2.157
7	Germinated Ponicam P+S	5.464	5.476

4.5 Plant Measurements

This study showed that the application of all treatments had no significant difference of mean at $p < 0.05$ for wheat and ponicam, except for corn for plant stem length and width, plant leaves number, plant leaf length, and width as described in Table 4.4, where corn has a significant difference between the control and the treated samples.

Table (4.4): Analysis of treatments for one-way ANOVA at $p < 0.05$

Plant Type	**Plant Measurement p-Value**				
	Stem Length	***Stem Width***	***Leaves Number***	***Leaf Length***	***Leaf Width***
Wheat	*0.982*	*0.941*	*0.773*	*0.589*	*0.624*
Corn	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*
Ponicam	*0.995*	*0.827*	*0.971*	*0.083*	*0.588*

4.5.1 Wheat

The investigation started with a period of three weeks in which measurements of the procedures were collected once every week for the first three weeks of the investigation. After that, they were inspected twice a month until they passed all of the tests. The comparison of the various interventions is depicted in Figure (4.1), which shows that the average stem length of wheat started at approximately nine centimeters and increased to range between 50 and 65 centimeters after eleven weeks of growth. It has been determined that the technique of treating sludge and PGPR wheat fresh water (SPWF) is the most efficient variety with direct competences.

The differences between CWF, CWB, PWF, PWB, SWF, SWB, SPWF, and SPWB for wheat stem breadth are illustrated in Figure (4.2). The width of the majority of the treatments began at one centimeter and increased significantly from there. While SPWF, SWF, SWB, and PWF received the highest increase to reach 15, 14, and 13 cm respectively, CWF and CWB gained the least stem width throughout the experiment. CWF and CWB increased their stem width by the least amount. All of the wheat treatments started with a range of 5 to 10 leaves, and by the end, they had reached a total capacity of 32 to 43 leaves, as shown in Figure (4.3), which depicts the difference between the treatments in terms of plant leaf count. The treatments with the most significant percentage of wheat leaves were SPWF and SPWB, while CWF and CWB had the lowest percentages.

As depicted in Figure 4.4, illustrating the differences among the treatments in terms of plant leaf length, the wheat treatments all initially exhibited a range of lengths varying between 4 and 12 centimeters. Eventually, they achieved a total range of lengths ranging from 33 to 46 cm. This was observed despite the treatments all commencing with the same initial length range. SPWF and SWF procedures received the highest scores, while CWF and CWB received the lowest scores. In Figure 4.7, the plant leaf width measured less than one centimeter at the beginning of the experiment but concluded with SPWF being the widest, approximately 4.5 cm, and CWB being the narrowest, measuring only 2.5 cm.

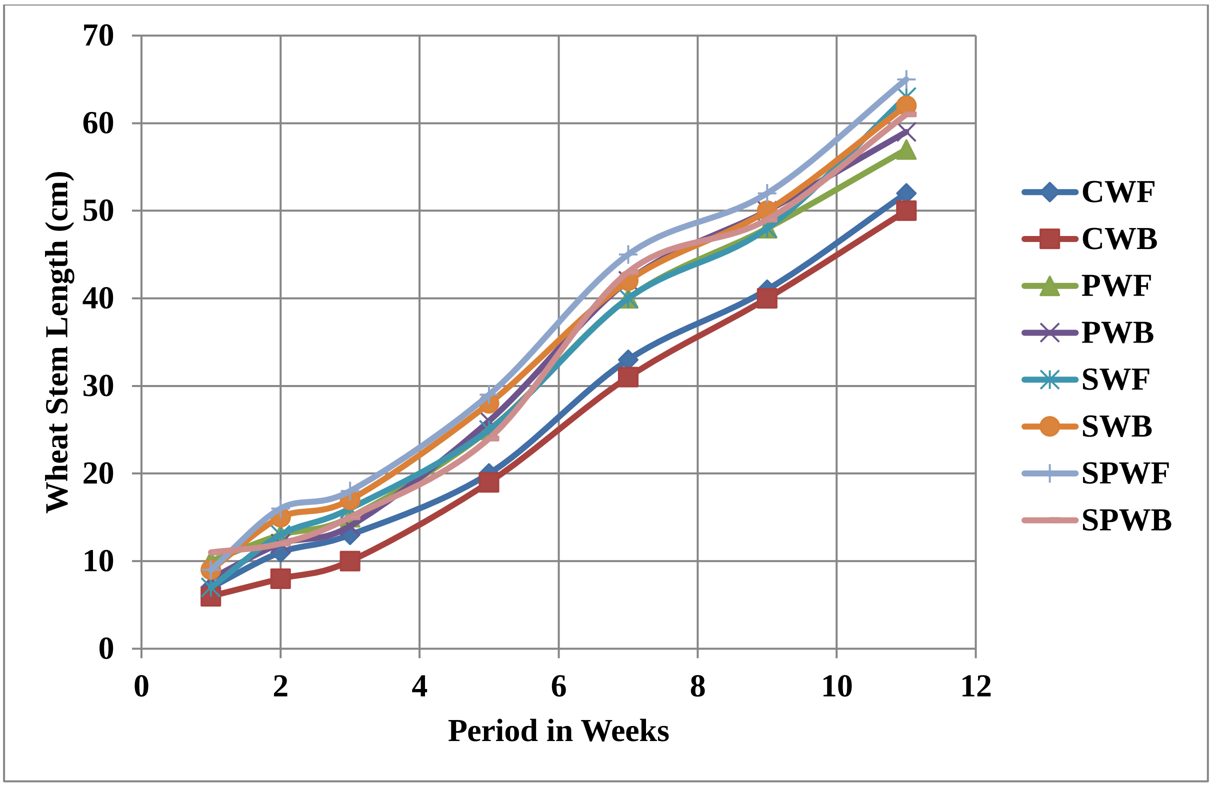
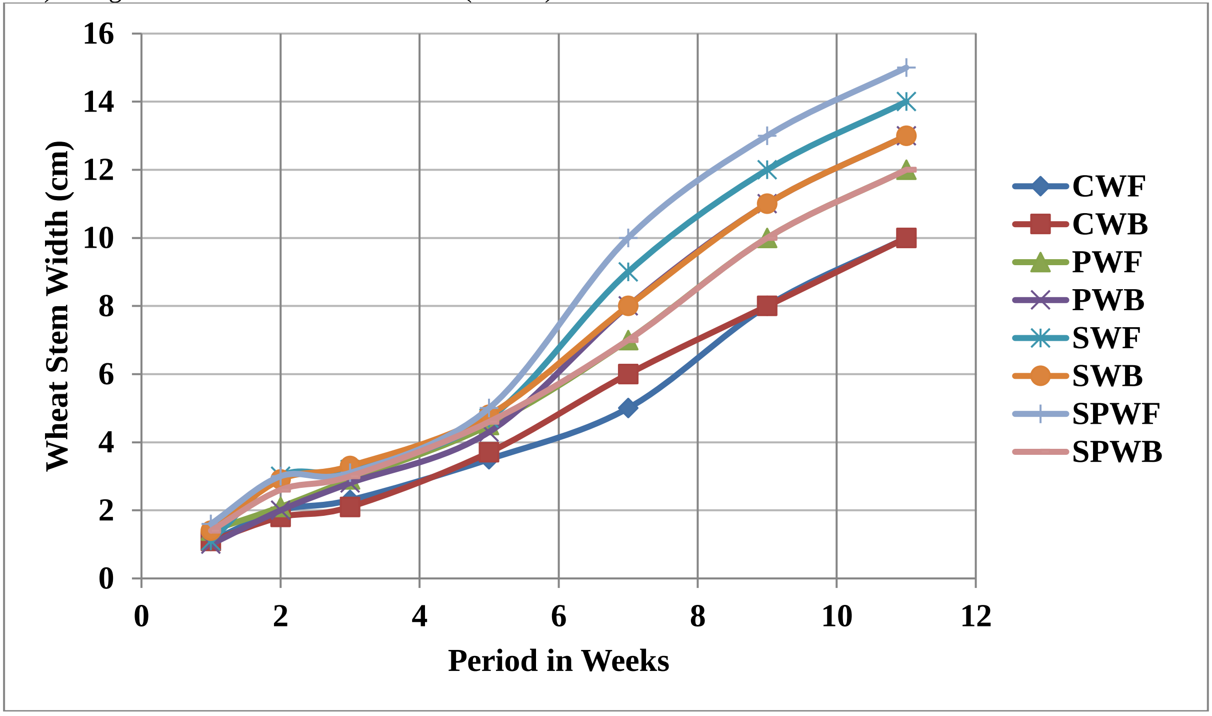


Figure (4.1): A comparison between wheat stem length (cm). (Blue rhomboid) Control Wheat Fresh Water (CWF), (red square) Control Wheat Brackish Water (CWB), (green triangle) PGPR Wheat Fresh Water (PWF), (violet cross) PGPR Wheat Brackish Water (PWB), (light blue star) Sludge Wheat Fresh Water (SWF), (Orange Circle) Sludge Wheat Brackish Water (SWB), (blue line) Sludge PGPR Wheat Fresh Water (SPWF), (purple line) Sludge PGPR Wheat Brackish Water (SPWB).



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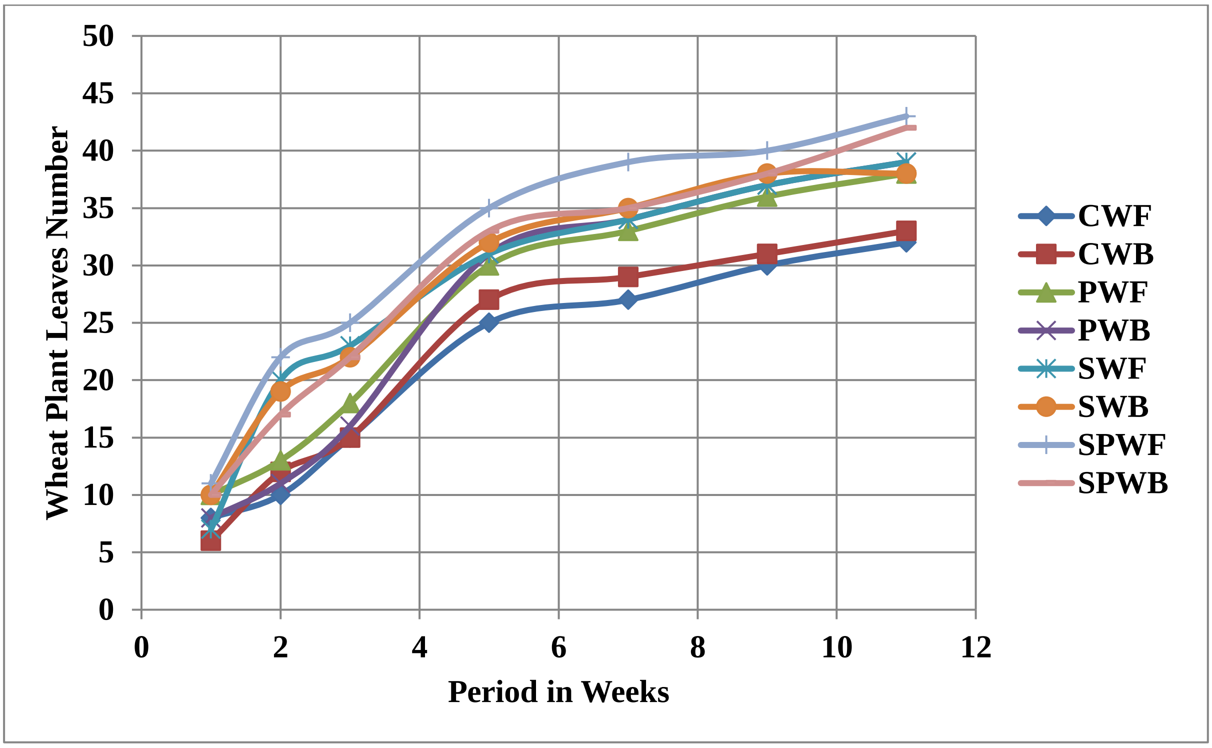
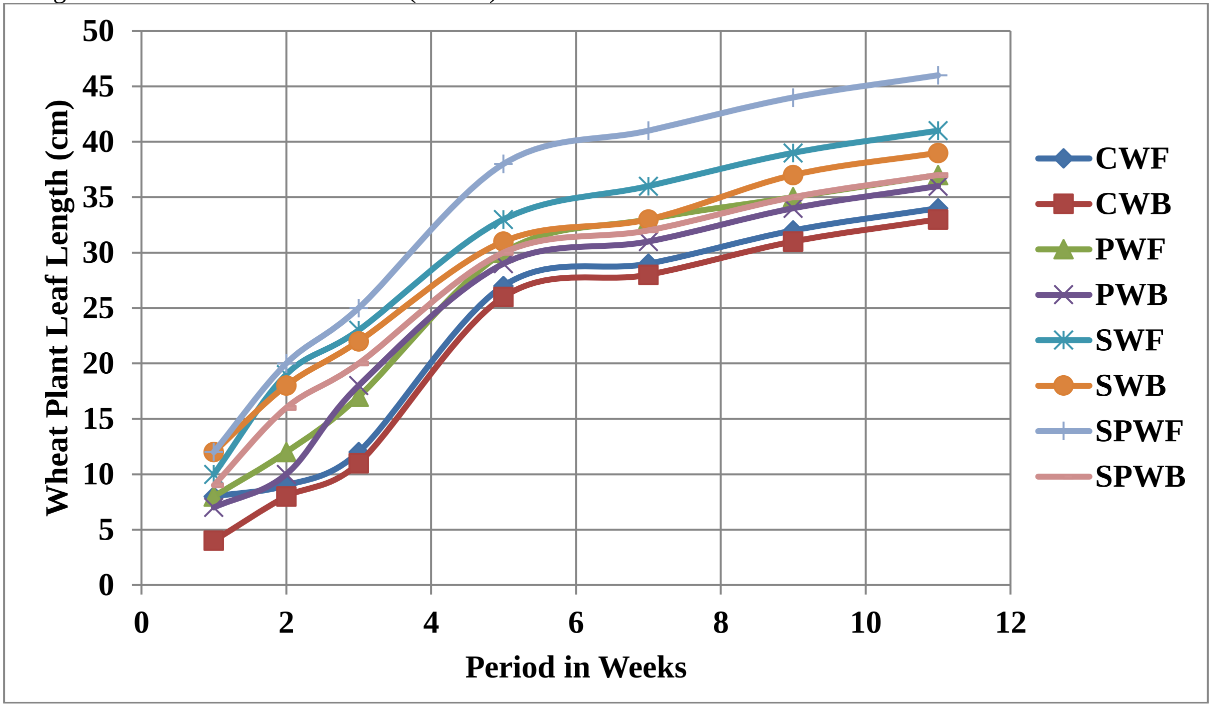


Figure (4.3): A comparison between wheat leaves number. (Blue rhomboid) Control Wheat Fresh Water (CWF), (red square) Control Wheat Brackish Water (CWB), (green triangle) PGPR Wheat Fresh Water (PWF), (violet cross) PGPR Wheat Brackish Water (PWB), (light blue star) Sludge Wheat Fresh Water (SWF), (Orange Circle) Sludge Wheat Brackish Water (SWB), (blue line) Sludge PGPR Wheat Fresh Water (SPWF), (purple line) Sludge PGPR Wheat Brackish Water (SPWB).



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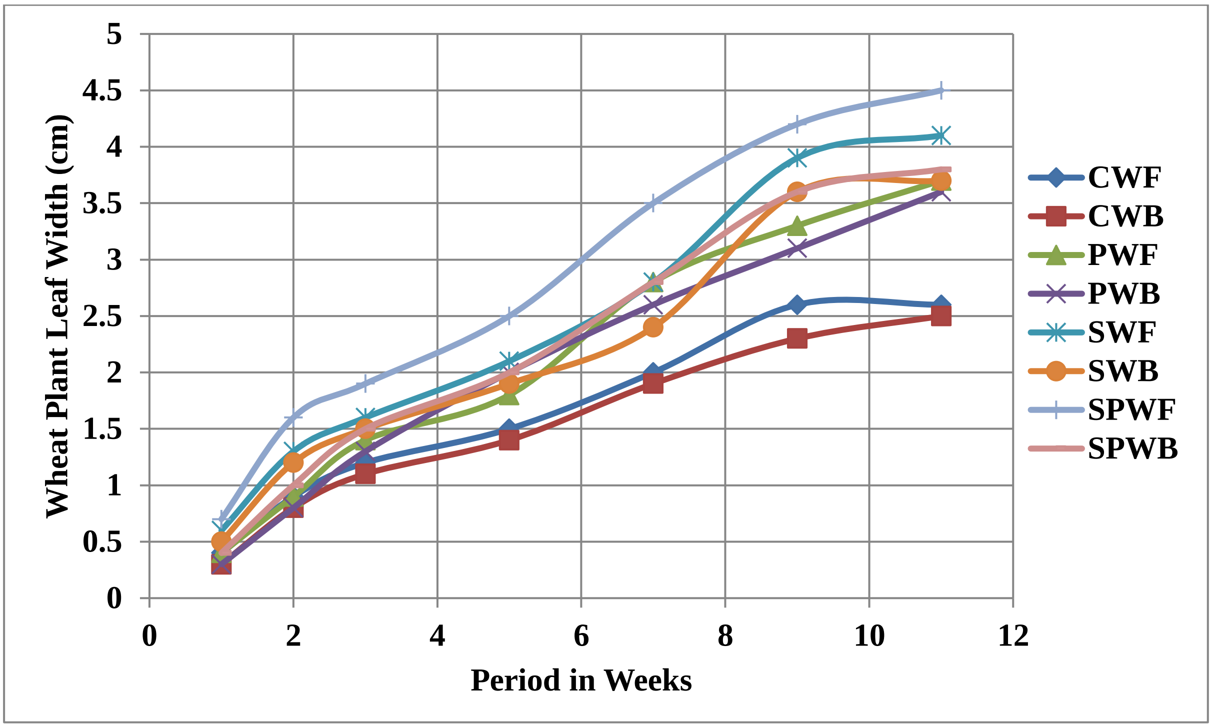

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4.5.2 Corn

The contrast between the interventions is depicted in figure (4.6), which demonstrates that after eleven weeks of development, the average corn stem length increased from a beginning point of 15 to 20 centimeters to a range of 116 to 138 centimeters. After the corn had been subjected to one of the three treatments for a period of eleven weeks, this increase became apparent. This increase became noticeable once the corn had grown to a height of fifteen to twenty millimeters in height. It has been discovered that the most profitable cultivars for straight competent treatment are the PGPR Corn Fresh Water (PNF) and PGPR Corn Brackish Water varieties (PNB).

Corn limb breadth measurements are presented in the following formats: CNF, CNB, PNF, PNB, SNF, SNB, S+PNF, and S+PNB. Figure 4.7 provides a description of the differences between each of these formats. The breadth of the majority of the treatments began at the beginning at a measurement that ranged from four to ten centimeters, but then significantly increased from that point on. In contrast, the SNF and SNB procedures did not result in any growth at all, whereas the growth that occurred from all of the other treatments was approximately forty centimeters. The corn treatments all started with a range of 5 to 7 leaves, and by the time the experiment was over, they had all reached a total range of 22 to 24 leaves, as illustrated in figure (4.8), which depicted the difference between the treatments in terms of plant leaf count. The one crop of corn was subjected to all of the treatments at the same time. In regions where the SNF and SNB did not experience the same level of expansion.

The corn treatments all started with a range of lengths that varied between 20 and 28 centimeters and ended up achieving a total range of lengths that varied between 51 and 55 centimeters, as can be seen in figure (4.9), which illustrates the differences between the treatments in terms of the length of the plant leaf. Despite the fact that all of the procedures started with the same length range, this was still the result. There was hardly any difference in the length of any of the varieties. When we started the experiment, the plant leaf breadth was approximately three centimeters, but by the time it was over, it was somewhere between 18 and 20 centimeters. This is shown in figure 4.10.

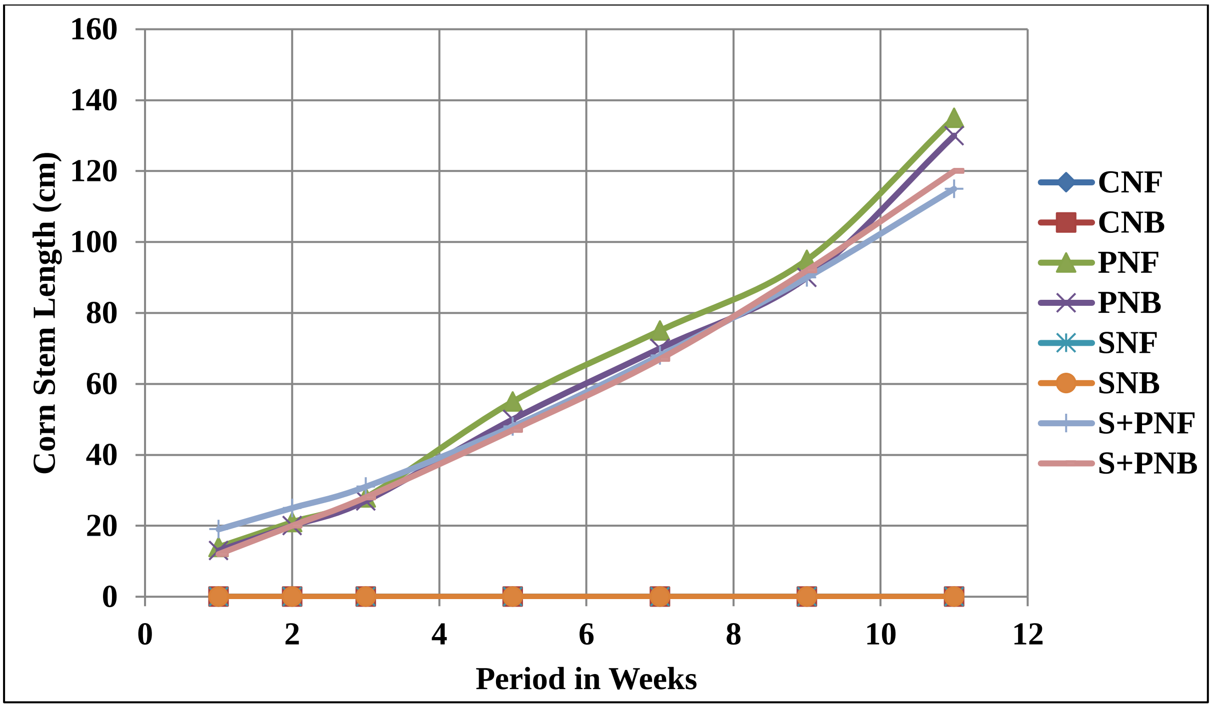

Figure (4.6): A comparison between Corn stem length (cm). (Blue rhomboid) Control Corn Fresh Water (CNF), (red square) Control Corn Brackish Water (CNB), (green triangle) PGPR Corn Fresh Water (PNF), (violet cross) PGPR Corn Brackish Water (PNB), (light blue star) Sludge Corn Fresh Water (SNF), (Orange Circle) Sludge Corn Brackish Water (SNB), (blue line) Sludge PGPR Corn Fresh Water (S+PNF), (purple line) Sludge PGPR Corn Brackish Water (S+PNB).

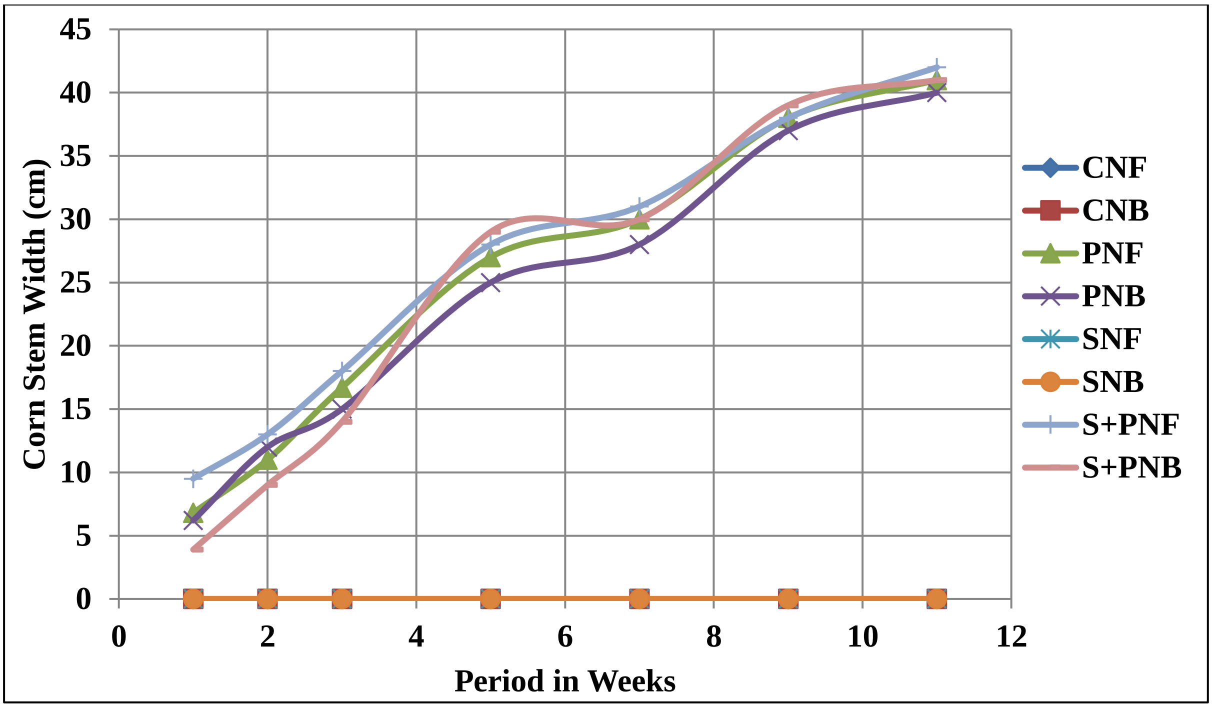

Figure (4.7): A comparison between Corn stem width (cm). (Blue rhomboid) Control Corn Fresh Water (CNF), (red square) Control Corn Brackish Water (CNB), (green triangle) PGPR Corn Fresh Water (PNF), (violet cross) PGPR Corn Brackish Water (PNB), (light blue star) Sludge Corn Fresh Water (SNF), (Orange Circle) Sludge Corn Brackish Water (SNB), (blue line) Sludge PGPR Corn Fresh Water (S+PNF), (purple line) Sludge PGPR Corn Brackish Water (S+PNB).

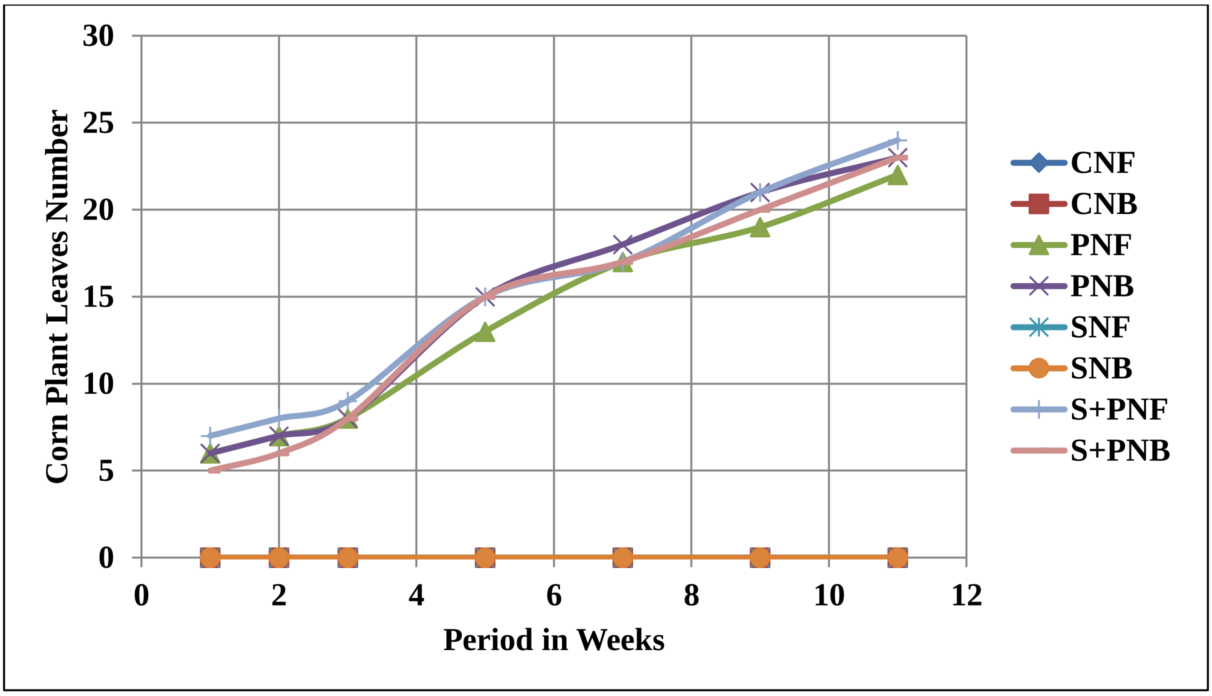

Figure (4.8): A comparison between Corn plant leaves number. (Blue rhomboid) Control Corn Fresh Water (CNF), (red square) Control Corn Brackish Water (CNB), (green triangle) PGPR Corn Fresh Water (PNF), (violet cross) PGPR Corn Brackish Water (PNB), (light blue star) Sludge Corn Fresh Water (SNF), (Orange Circle) Sludge Corn Brackish Water (SNB), (blue line) Sludge PGPR Corn Fresh Water (S+PNF), (purple line) Sludge PGPR Corn Brackish Water (S+PNB).

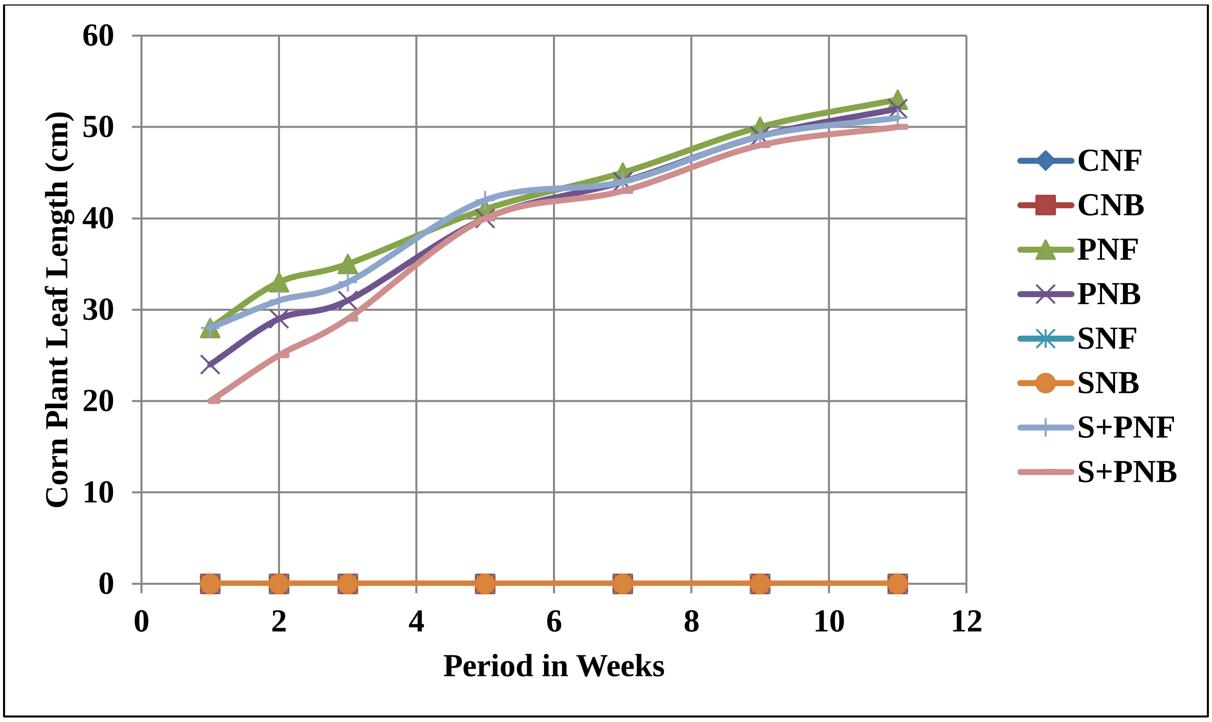

Figure (4.9): A comparison between Corn plant leaves length (cm). (Blue rhomboid) Control Corn Fresh Water (CNF), (red square) Control Corn Brackish Water (CNB), (green triangle) PGPR Corn Fresh Water (PNF), (violet cross) PGPR Corn Brackish Water (PNB), (light blue star) Sludge Corn Fresh Water (SNF), (Orange Circle) Sludge Corn Brackish Water (SNB), (blue line) Sludge PGPR Corn Fresh Water (S+PNF), (purple line) Sludge PGPR Corn Brackish Water (S+PNB).

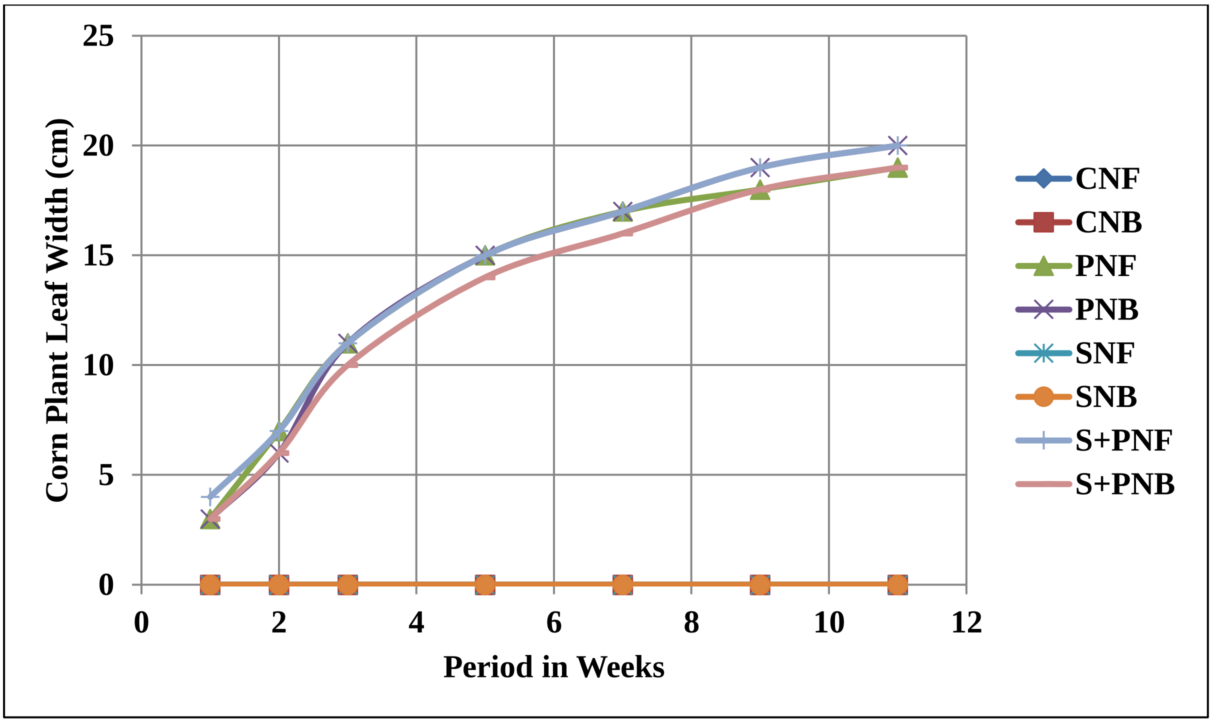

Figure (4.10): A comparison between Corn leaves width (cm). (Blue rhomboid) Control Corn Fresh Water (CNF), (red square) Control Corn Brackish Water (CNB), (green triangle) PGPR Corn Fresh Water (PNF), (violet cross) PGPR Corn Brackish Water (PNB), (light blue star) Sludge Corn Fresh Water (SNF), (Orange Circle) Sludge Corn Brackish Water (SNB), (blue line) Sludge PGPR Corn Fresh Water (S+PNF), (purple line) Sludge PGPR Corn Brackish Water (S+PNB).

4.5.3 Ponicam

The contrast between the interventions is depicted in figure (4.11), which shows that after eleven weeks of development, the average ponicam stem length increased from 5 to 15 centimeters at the outset of development to a range of 65 to 85 centimeters. This was an enormous advance over the original length. This increase became noticeable eleven weeks after the ponicam had been subjected to one of the three interventions. Most treatments besides Control Ponicam Fresh Water (CKF) and Control Ponicam Brackish Water (CPBW) have proven to be the most profitable cultivars for direct competent treatment. (CKB). In parallel, ponicam stem width is depicted in figure (4.12), where all treatments began with stem widths of less than 5 centimeters and progressively increased to 26 centimeters for S+PKF followed by S+PKB, SKB, PKF, and PKB respectively, while CKF and CKB had stem widths of approximately 17 and 18 centimeters.

In addition, the quantity of ponicam leaves, which was described in figure 4.13, showed that the majority of types had between four and nine leaves, and all of them, with the exception of CKF, reached over twenty leaves for each cultivar after eleven weeks. On the other hand, as seen in figure 4.14, plant leaves started with varying numbers, ranging from 10 to 26 leaves, but ended with approximately fifty leaves per cultivar. Well control samples (CKF and CKB) were too low in comparison to the other trials. The breadth of the leaves on the ponicam plant is depicted in figure 4.15. At the beginning of the experiment, the width of the leaves varied between one and five centimeters, but by the end of the experiment, it had increased to between 11 and 13 centimeters.

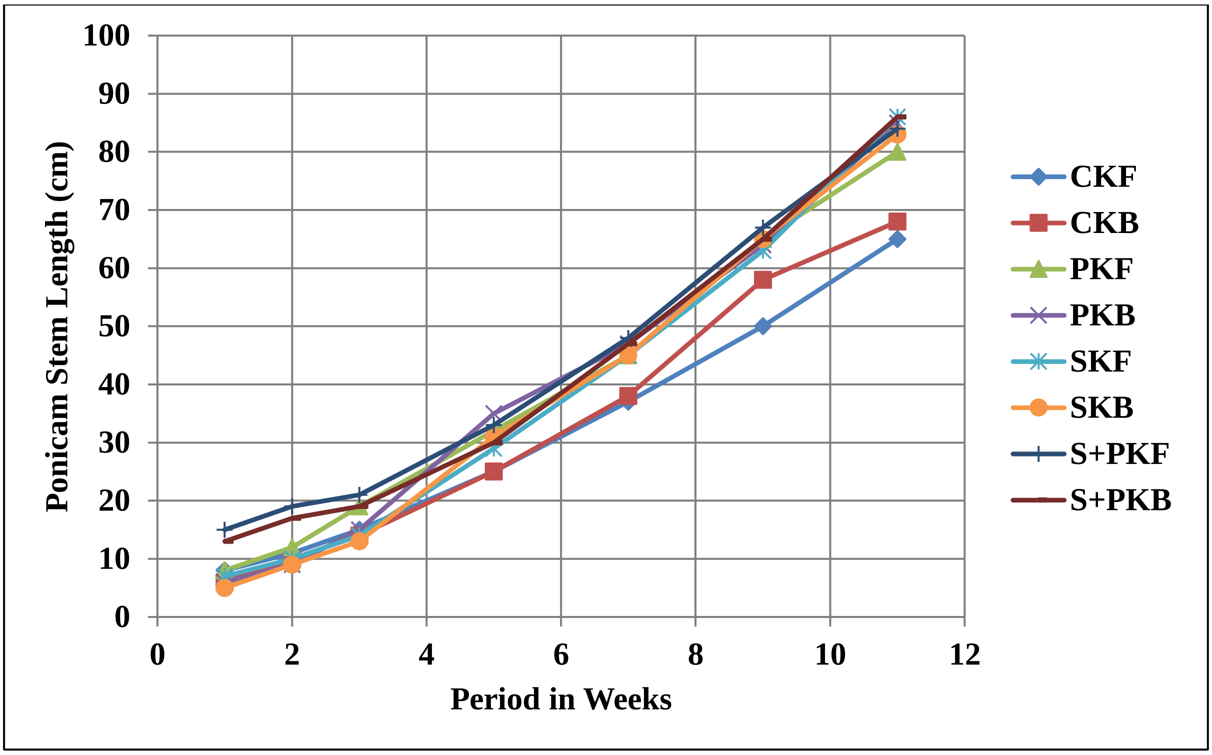

Figure (4.11): A comparison between Ponicam stem length (cm). (Blue rhomboid) Control Ponicam Fresh Water (CKF), (red square) Control Ponicam Brackish Water (CKB), (green triangle) PGPR Ponicam Fresh Water (PKF), (violet cross) PGPR Ponicam Brackish Water (PKB), (light blue star) Sludge Ponicam Fresh Water (SKF), (Orange Circle) Sludge Ponicam Brackish Water (SKB), (blue line) Sludge PGPR Ponicam Fresh Water (S+PKF), (purple line) Sludge PGPR Ponicam Brackish Water (S+PKB).

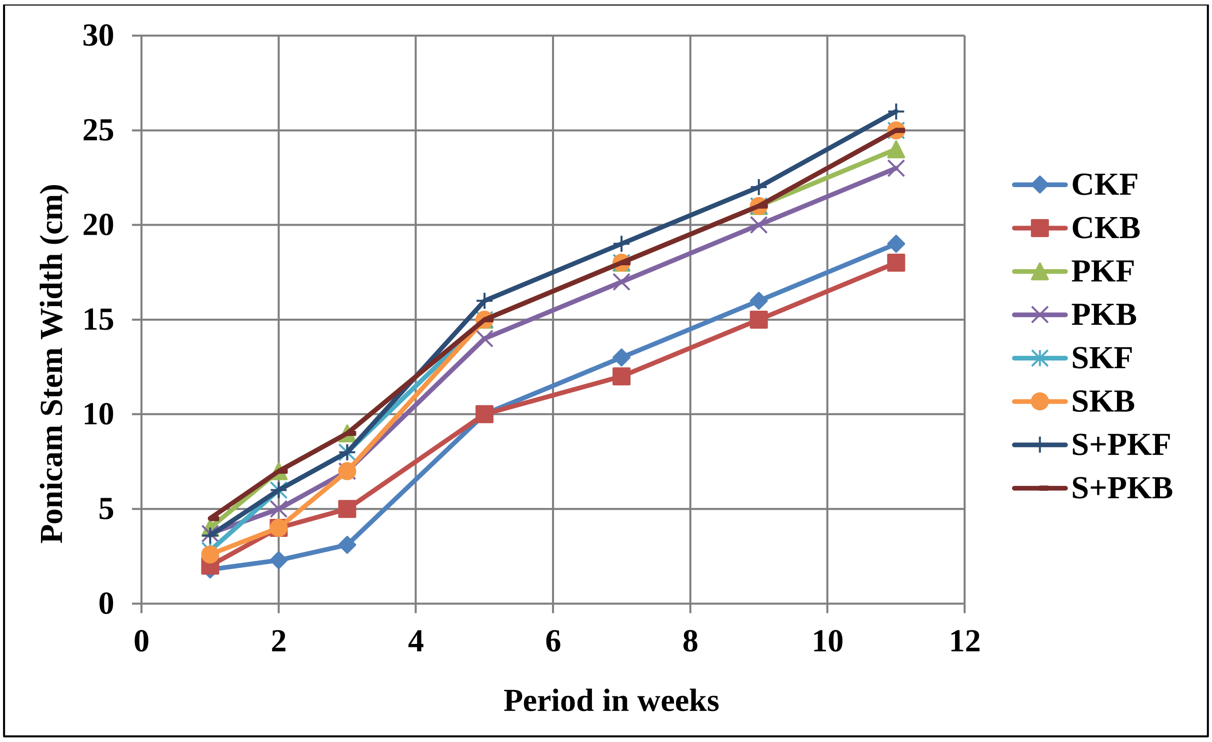

Figure (4.12): A comparison between Ponicam stem width (cm). (Blue rhomboid) Control Ponicam Fresh Water (CKF), (red square) Control Ponicam Brackish Water (CKB), (green triangle) PGPR Ponicam Fresh Water (PKF), (violet cross) PGPR Ponicam Brackish Water (PKB), (light blue star) Sludge Ponicam Fresh Water (SKF), (Orange Circle) Sludge Ponicam Brackish Water (SKB), (blue line) Sludge PGPR Ponicam Fresh Water (S+PKF), (purple line) Sludge PGPR Ponicam Brackish Water (S+PKB).

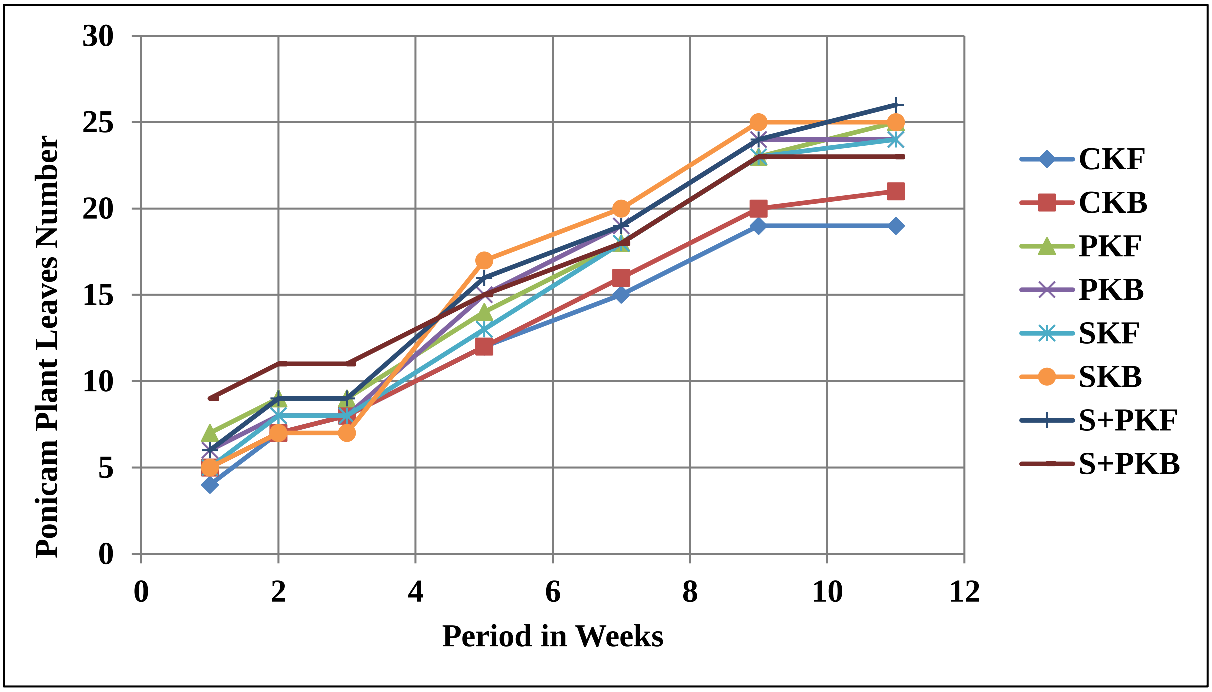

Figure (4.13): A comparison between Ponicam leaves number (cm). (Blue rhomboid) Control Ponicam Fresh Water (CKF), (red square) Control Ponicam Brackish Water (CKB), (green triangle) PGPR Ponicam Fresh Water (PKF), (violet cross) PGPR Ponicam Brackish Water (PKB), (light blue star) Sludge Ponicam Fresh Water (SKF), (Orange Circle) Sludge Ponicam Brackish Water (SKB), (blue line) Sludge PGPR Ponicam Fresh Water (S+PKF), (purple line) Sludge PGPR Ponicam Brackish Water (S+PKB).

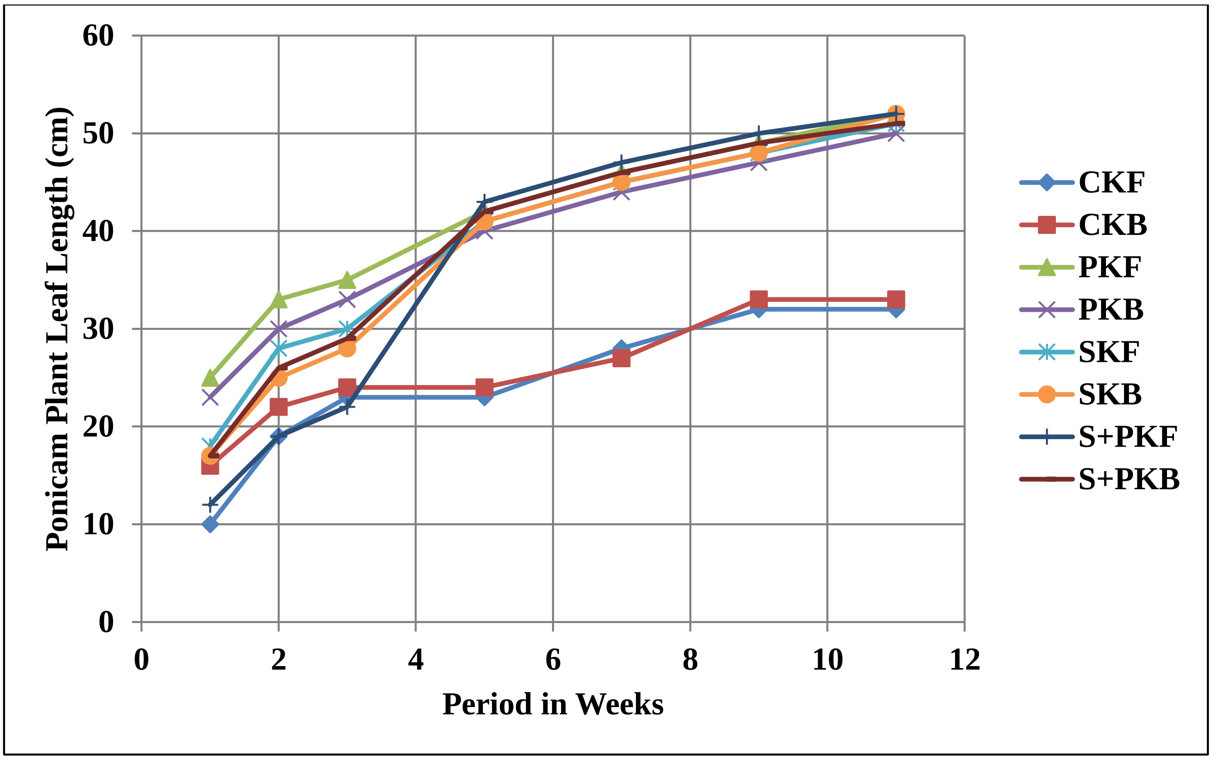

Figure (4.14): A comparison between Ponicam leaves length (cm). (Blue rhomboid) Control Ponicam Fresh Water (CKF), (red square) Control Ponicam Brackish Water (CKB), (green triangle) PGPR Ponicam Fresh Water (PKF), (violet cross) PGPR Ponicam Brackish Water (PKB), (light blue star) Sludge Ponicam Fresh Water (SKF), (Orange Circle) Sludge Ponicam Brackish Water (SKB), (blue line) Sludge PGPR Ponicam Fresh Water (S+PKF), (purple line) Sludge PGPR Ponicam Brackish Water (S+PKB).

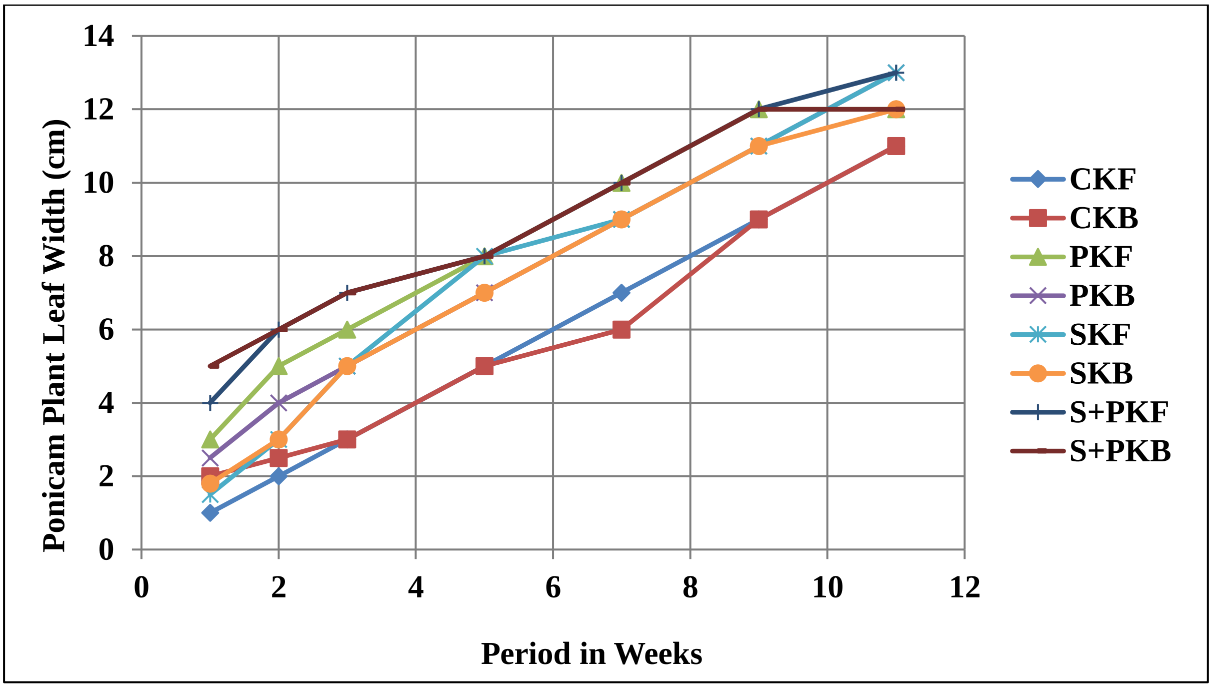

Figure (4.15): A comparison between Ponicam leaves width (cm). (Blue rhomboid) Control Ponicam Fresh Water (CKF), (red square) Control Ponicam Brackish Water (CKB), (green triangle) PGPR Ponicam Fresh Water (PKF), (violet cross) PGPR Ponicam Brackish Water (PKB), (light blue star) Sludge Ponicam Fresh Water (SKF), (Orange Circle) Sludge Ponicam Brackish Water (SKB), (blue line) Sludge PGPR Ponicam Fresh Water (S+PKF), (purple line) Sludge PGPR Ponicam Brackish Water (S+PKB).

Chapter Five: Recommendations & Conclusions

5.1 Recommendations

- This study recommends using plant growth-promoting rhizobacteria in combination of sludge with the application of fresh water for irrigation of corn.
- This study suggests the need for the development of additional research endeavors to conduct a comprehensive investigation into the activities of Plant Growth-Promoting Bacteria (PGPB) and the utilization of sludge in greater depth.

5.2 Conclusion

In conclusion, the investigation into germinated corn, ponicam, and wheat growth under varying irrigation conditions revealed significant insights into the challenges posed by soil salinity and the potential benefits of innovative agricultural practices. The study demonstrated that germinated corn exhibited its maximum growth, salt accumulation, and biomass measurement between October 2020 and January 2021, with distinct variations observed in treatments irrigated with brackish water, fresh water, and the control. The salinity of the soil hindered valid comparisons between different irrigation methods for corn and ponicam, and the control plants struggled to thrive, indicating the adverse impact of saline stress. The visual cues of green color in germinated treatments contrasted with the yellowish color of the control, serving as a visible indicator of saline stress even in treatments with varied irrigation. In the case of wheat, there was no significant difference in lengths measured between the germinated and control plants. These findings highlight the complexity of plant responses to saline conditions and underscore the need for sustainable agricultural solutions to address soil salinity.

The collective output from this study, along with previous research, underscores the potential benefits of employing plant growth-promoting bacteria, sewage sludge, and innovative technologies to enhance soil fertility, promote plant growth, and recover nutrients. These approaches offer promising avenues for mitigating the challenges posed by soil salinity and advancing sustainable agriculture practices. The emphasis on addressing soil salinity in various studies emphasizes the urgency and importance of adopting holistic and environmentally conscious strategies for ensuring the long-term health and productivity of agricultural ecosystems.

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Appendix

A. Wheat Results

Table (A.1): Wheat Stem Length (cm) / week

Treatment	***Wheat Stem Length (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CWF	7	11	13	20	33	41	52
CWB	6	8	10	19	31	40	50
PWF	10	13	15	25	40	48	57
PWB	8	12	14	26	42	50	59
SWF	7	13	16	25	40	48	63
SWB	9	15	17	28	42	50	62
SPWF	9	16	18	29	45	52	65
SPWB	11	12	15	24	43	49	61

Table (A.2): Wheat Stem Width (cm) / week

Treatment	***Wheat Stem Width (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CWF	1.1	2	2.3	3.5	5	8	10
CWB	1.1	1.8	2.1	3.7	6	8	10
PWF	1.4	2.1	2.9	4.5	7	10	12
PWB	1	2	2.8	4.3	8	11	13
SWF	1.1	3	3.2	4.7	9	12	14
SWB	1.4	2.9	3.3	4.8	8	11	13
SPWF	1.6	3	3.1	5	10	13	15
SPWB	1.4	2.6	3	4.6	7	10	12

Table (A.3): Wheat Plant Leaves Number / week

Treatment	***Wheat Plant Leaves Number / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CWF	8	10	15	25	27	8	10
CWB	6	12	15	27	29	6	12
PWF	10	13	18	30	33	10	13
PWB	8	11	16	31	34	8	11
SWF	7	20	23	31	34	7	20
SWB	10	19	22	32	35	10	19
SPWF	11	22	25	35	39	11	22
SPWB	10	17	22	33	35	10	17

Table (A.4): Wheat Plant Leaves Length (cm) / week

Treatment	***Wheat Plant Leaves Length (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CWF	8	9	12	27	29	8	9
CWB	4	8	11	26	28	4	8
PWF	8	12	17	30	33	8	12
PWB	7	10	18	29	31	7	10
SWF	10	19	23	33	36	10	19
SWB	12	18	22	31	33	12	18
SPWF	12	20	25	38	41	12	20
SPWB	9	16	20	30	32	9	16

Table (A.5): Wheat Plant Leaves Width (cm) / week

Treatment	***Wheat Plant Leaves Width (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CWF	0.4	0.9	1.2	1.5	2	0.4	0.9
CWB	0.3	0.8	1.1	1.4	1.9	0.3	0.8
PWF	0.4	0.9	1.4	1.8	2.8	0.4	0.9
PWB	0.3	0.8	1.3	2	2.6	0.3	0.8
SWF	0.6	1.3	1.6	2.1	2.8	0.6	1.3
SWB	0.5	1.2	1.5	1.9	2.4	0.5	1.2
SPWF	0.7	1.6	1.9	2.5	3.5	0.7	1.6
SPWB	0.4	1	1.5	2	2.8	0.4	1

B. Corn Results

Table (B.1): Corn Stem Length (cm) / week

Treatment	***Corn Stem Length (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CNF	0	0	0	0	0	0	0
CNB	0	0	0	0	0	0	0
PNF	14	21	28	55	75	95	135
PNB	13	20	27	50	70	90	130
SNF	0	0	0	0	0	0	0
SNB	0	0	0	0	0	0	0
S+PNF	19	25	31	48	68	90	115
S+PNB	12	20	28	47	67	92	120

Table (B.2): Corn Stem Width (cm) / week

Treatment	***Corn Stem Width (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CNF	0	0	0	0	0	0	0
CNB	0	0	0	0	0	0	0
PNF	6.8	11	16.7	27	30	38	41
PNB	6.2	12	15	25	28	37	40
SNF	0	0	0	0	0	0	0
SNB	0	0	0	0	0	0	0
S+PNF	9.5	13	18	28	31	38	42
S+PNB	3.9	9	14	29	30	39	41

Table (B.3): Corn Plant Leaves Number / week

Treatment	***Corn Plant Leaves Number / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CNF	0	0	0	0	0	0	0
CNB	0	0	0	0	0	0	0
PNF	6	7	8	13	17	19	22
PNB	6	7	8	15	18	21	23
SNF	0	0	0	0	0	0	0
SNB	0	0	0	0	0	0	0
S+PNF	7	8	9	15	17	21	24
S+PNB	5	6	8	15	17	20	23

Table (B.4): Corn Leaves Length (cm) / week

Treatment	***Corn Leaves Length (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CNF	0	0	0	0	0	0	0
CNB	0	0	0	0	0	0	0
PNF	28	33	35	41	45	50	53
PNB	24	29	31	40	44	49	52
SNF	0	0	0	0	0	0	0
SNB	0	0	0	0	0	0	0
S+PNF	28	31	33	42	44	49	51
S+PNB	20	25	29	40	43	48	50

Table (B.5): Corn Leaves Width (cm) / week

Treatment	***Corn Leaves Width (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CNF	0	0	0	0	0	0	0
CNB	0	0	0	0	0	0	0
PNF	3	7	11	15	17	18	19
PNB	3	6	11	15	17	19	20
SNF	0	0	0	0	0	0	0
SNB	0	0	0	0	0	0	0
S+PNF	4	7	11	15	17	19	20
S+PNB	3	6	10	14	16	18	19

C. Ponicam Results

Table (C.1): Ponicam Stem Length (cm) / week

Treatment	***Ponicam Stem Length (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CKF	8	11	15	25	37	50	65
CKB	6	10	14	25	38	58	68
PKF	8	12	19	32	45	65	80
PKB	6	9	15	35	47	64	85
SKF	7	10	14	29	45	63	86
SKB	5	9	13	31	45	65	83
S+PKF	15	19	21	33	48	67	84
S+PKB	13	17	19	30	47	65	86

Table (C.2): Ponicam Stem Width (cm) / week

Treatment	***Ponicam Stem Width (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CKF	1.8	2.3	3.1	10	13	16	19
CKB	2	4	5	10	12	15	18
PKF	4	7	9	15	18	21	24
PKB	3.7	5	7	14	17	20	23
SKF	2.8	6	8	15	18	21	25
SKB	2.6	4	7	15	18	21	25
S+PKF	3.6	6	8	16	19	22	26
S+PKB	4.5	7	9	15	18	21	25

Table (C.3): Ponicam Plant Leaves Number / week

Treatment	***Ponicam Plant Leaves Number / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CKF	4	7	8	12	15	19	19
CKB	5	7	8	12	16	20	21
PKF	7	9	9	14	18	23	25
PKB	6	8	8	15	19	24	24
SKF	5	8	8	13	18	23	24
SKB	5	7	7	17	20	25	25
S+PKF	6	9	9	16	19	24	26
S+PKB	9	11	11	15	18	23	23

Table (C.4): Ponicam Plant Leaves Length (cm) / week

Treatment	***Ponicam Plant Leaves Length (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CKF	10	19	23	23	28	32	32
CKB	16	22	24	24	27	33	33
PKF	25	33	35	42	46	49	52
PKB	23	30	33	40	44	47	50
SKF	18	28	30	41	45	48	51
SKB	17	25	28	41	45	48	52
S+PKF	12	19	22	43	47	50	52
S+PKB	17	26	29	42	46	49	51

Table (C.5): Ponicam Plant Leaves Width (cm) / week

Treatment	***Ponicam Plant Leaves Width (cm) / week***						
	Week one	**Week two**	**Week three**	**Week five**	**Week seven**	**Week nine**	**Week eleven**
CKF	1	2	3	5	7	9	11
CKB	2	2.5	3	5	6	9	11
PKF	3	5	6	8	10	12	12
PKB	2.5	4	5	7	9	11	13
SKF	1.5	3	5	8	9	11	13
SKB	1.8	3	5	7	9	11	12
S+PKF	4	6	7	8	10	12	13
S+PKB	5	6	7	8	10	12	12