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Utilization of Subsurface Drainage to Reduce Salinity under Different Saline Soil Mixture Ratios and Their Effects on the Growth of Red Spinach (*Amaranthus tricolor*)

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Abstract
Soil salinity is a significant limiting factor in plant growth, particularly in areas affected by salt accumulation. This study aims to analyze the effectiveness of underground drainage in reducing soil salinity through the leaching method and its impact on the growth of spinach (*Amaranthus tricolor*). The experiment involved applying saline soil mixtures at ratios of 25%, 50%, 75%, and 100% alongside non-saline soil while utilizing underground drainage to expedite the salt leaching process. The parameters observed included pH, electrical conductivity (EC), sodium (Na) content, and plant growth. Observations were conducted at 1, 10, 20, and 30 days, with three replications for each treatment. The results indicated that underground drainage significantly reduced soil salinity levels in a relatively short period. The decrease in salt concentration positively influenced spinach growth, particularly in treatments with lower saline soil mixture ratios. These findings suggest that underground drainage can serve as an effective solution to mitigate agricultural land salinity, thereby enhancing plant productivity.

Keywords: Electrical Conductivity (EC), Observation Time Interval, Plant Productivity, Salt Leaching, Sodium Content (Na),

1. Introduction

Indonesia has a long coastline with many saline lands, making it challenging to grow productive crops. Seawater intrusion exacerbated by sea level rise and global warming causes salt accumulation in the soil, inhibiting plant growth due to osmotic pressure. Saline soil is generally formed due to seawater evaporation that leaves salt residues, especially in areas with low rainfall that do not allow the natural leaching of salt in the soil (Nasyirah et al., 2015). In addition, the opening of new land and the lack of irrigation systems also accelerate the increase in salinity, causing the degradation of agricultural land.

Damage to productive land due to salinity threatens global food security. Land conversion and excessive use of chemical fertilizers increase salt levels in the soil, ultimately reducing soil fertility and inhibiting plant growth (Handriatni, 2021). Spinach (*Amaranthus tricolor*) is a plant sensitive to high salinity, so its productivity can decrease significantly if planted on degraded land.

If left untreated, high salinity will inhibit plant roots' absorption of water and nutrients, cause physiological stress, reduce crop yields, and harm farmers economically. One solution that can be applied is underground drainage, which functions to wash salt from the soil through excessive flooding. One critical study was conducted by (Nasyirah et al., 2015) from IPB, which analyzed the rate of saline soil leaching using a subsurface drainage system. This study aims to evaluate the accuracy of the ILRI formula (1994) in calculating the leaching rate. The experimental results showed that the leaching time to achieve the desired salt concentration varied depending on the percolation rate, with values of 0.07, 0.13, and 0.08 days for percolation rates of 1035.73, 1614.12, and 1888.52 mm/day respectively. However, there are differences between the experimental results and calculations using the ILRI formula, so it is necessary to develop the formula by adding correction coefficients for the field capacity (Wfc) values of 0.076, 0.078, and 0.042 for experiments 1, 2, and

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3 so that the calculation results are close to real conditions.

This study aims to examine the effectiveness of underground drainage in reducing soil salinity and its impact on spinach growth. With a mixture ratio of productive and saline soil of 25%, 50%, 75%, and 100% and a trial duration of 30 days, this study is expected to provide insight into strategies for increasing agricultural productivity in high-salinity land to support sustainable agriculture in Indonesia.

2. Material and Methods

2.1. Place and Time of Research

This research was conducted in Petiken Village, Driyorejo District, Gresik Regency, East Java, Indonesia, located at coordinates 7°20'19.9" South Latitude and 112°38'17.7" East Longitude, with an altitude of about 11 meters above sea level. The research activities took place from September to October 2024. Soil sample analysis was conducted at the Soil Laboratory of the Agricultural Instrument Standards Implementation Center (BSIP) East Java, located at Jl. Raya Karangploso Km. 04, Kepuharjo Village, Karangploso District, Malang Regency, East Java.

2.2. Materials and Tools

The tools used in the study were a groundwater flow experiment box equipped with a porous PVC pipe as a surface drainage. This pipe had holes with a diameter of 3.5 mm and a distance between holes of 5 cm. Tools such as analytical balance, volumetric pipette, measuring flask, Erlenmeyer, burette, beaker, dropper pipette, and spray bottle are needed for laboratory research. While the materials used in this experiment were spinach seeds, clean water, organic liquid fertilizer, gravel stones, and soil samples that had been collected, and the chemicals used were KCL, aquades, ammonium acetate, ethanol, HCl, NaCl, quartz sand, concentrated sulfuric acid, potassium dichromate.

2.3. Research Methods

This study used a Completely Randomized Design (CRD) method with treatments in the form of soil salinity levels, namely the ratio of saline soil mixtures of 25%, 50%, 75% and 100% with no saline. Observations were carried out for 30 days with an observation interval of every 10 days. Laboratory analysis measured pH parameters, electrical conductivity (EC), porosity, and sodium (Na) levels in the soil. Spinach planting was carried out in experimental fields to evaluate the effect of salinity treatment on plant growth.

2.4. Underground Drainage

The drainage system removes excess water that dissolves salts in the soil, allowing dissolved salts to be effectively discharged. With perforated pipes installed underground, water and salt solutions are drained into the drain, maintaining the balance of salt levels and land fertility. A mini underground drainage model is used to drain excess water and dissolve salts through a system of pipes connected horizontally and vertically. The main components of this system include drainage pipes, drains, water sources, and filters to prevent soil particles (small crushed stones) from entering. Watering uses 5 liters of water, and the drainage output water is collected for analysis, with the water volume adjusted based on the field capacity of the soil in the pot method.

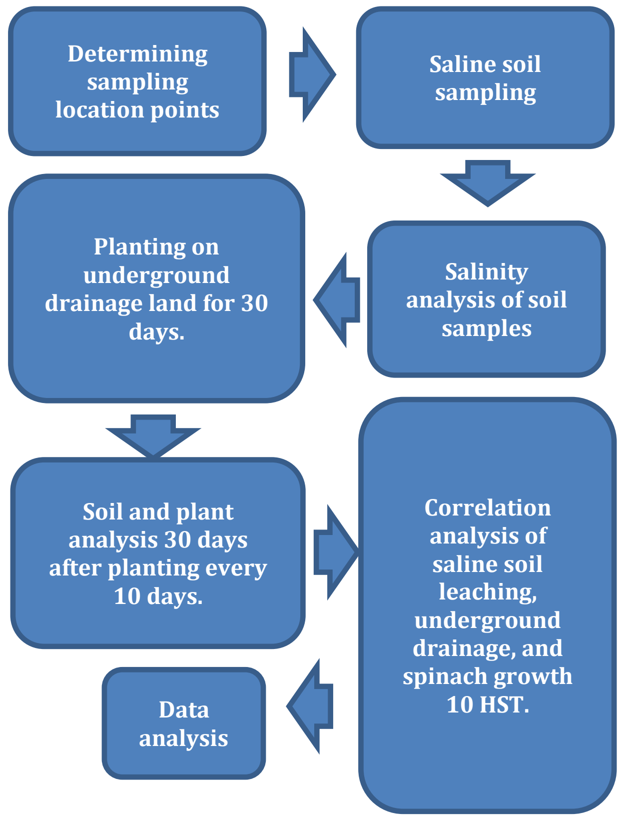

Figure 1. Research flow diagram

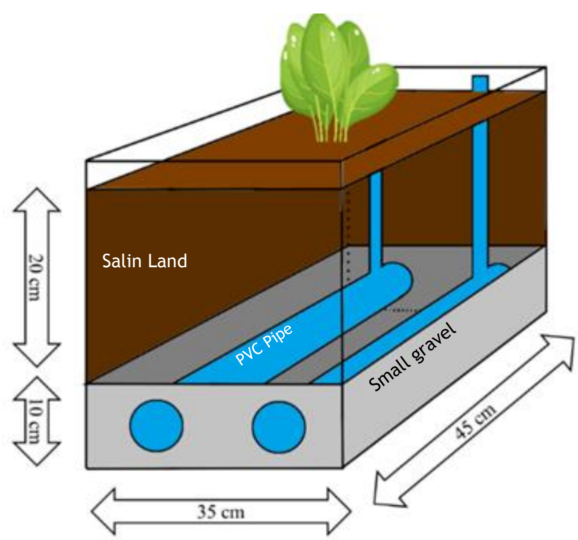

Figure 2. Example of an underground drainage test box

2.5. Planting spinach

Land preparation for the experimental box begins with organic fertilizer spread thinly over the soil's surface. After that, the land is watered thoroughly to provide sufficient moisture. After the experimental land is ready, spinach seeds are spread in the grooves determined according to the experimental land plan (Figure 1). The seeds are then covered with a layer of soil approximately 1 cm thick, and the land is watered again.

2.6. Spinach Maintenance

Spinach maintenance includes fertilization and watering. Fertilization uses manure spread evenly over the soil's surface once a week. Watering is done once a day, namely in the morning. The volume of water to be watered is ≈ 5 liters. This watering also functions as part of the saline soil-washing process.

2.7. Data Analysis

For EC and pH data analysis, the ANOVA data analysis model will be used using the Microsoft Excel 365 Application to analyze whether there is a significant difference between the saline soil mixture ratio treatment on EC and pH results, with the soil mixture ratio treatment test factor (25%, 50%, 75%, 100%) with 3 repetitions for each treatment and observation time from day 1,10, 20, 30. Furthermore, the data is tested for honest significant difference (HSD) at a level of 5% with the following equation:

$$BNJ_{0,05} = t_{0,05(p;db\ galat)} \times \sqrt{\frac{KT\ galat}{r}}$$

Information :

$BNJ_{0.05}$ = Honestly Real Difference at 5% level

$t_{0.05(p;db\ error)}$ = Table t at 5% level; (number of treatments p and degrees of error freedom)

KT error = Middle Square Error

r = number of repetitions

3. Results and Discussion

3.1. 3.1. pH Value of Drainage Water

The results show a trend of changes in water pH values for 30 days, indicating fluctuations in pH values in various treatments of saline to non-saline soil mixture ratios (S100, S75, S50, and S25). Generally, pH values tend to increase from the first to the 10th day, then stabilize until the 30th.

The first day showed that the soil with a higher saline mixture (S50 and S75) had a lower pH value than S100 and S25. The 10th day showed a significant increase in pH in all treatments, especially S25 (from 6.76 to 7.85) and S100 (from 7.25 to 8.21). The pH values for all treatments increased, most likely due to the drainage's ability to remove excess hydrogen ions (H^+) and replace them with base ions that increase pH. This point shows that drainage has effectively reduced ions that cause acidity in the soil. This point is in line with (Supwatul Hakim et al., 2023) the concept of alkalinity, which is the capacity of water to neutralize acid, also known as Acid Neutralizing Capacity (ANC). In other words, alkalinity is the amount of negative ions (anions) in water that can neutralize positive ions (cations) of hydrogen.

Table 1. Average results of pH measurements of Drainage Water

Treatment	Average pH day-			
	1	10	20	30
S100	7.25 ± 0.06 c	8.21 ± 0.1 c	8.20 ± 0.17	7.98 ± 0.18
S75	7.06 ± 0.19 bc	7.64 ± 0.32 ab	7.87 ± 0.14	7.91 ± 0.11
S50	6.94 ± 0.18 ab	7.47 ± 0.37 a	7.80 ± 0.17	7.77 ± 0.13
S25	6.76 ± 0.1 a	7.85 ± 0.16 b	7.97 ± 0.47	7.72 ± 0.20
BNJ 5%	0.19	0.31	tn	tn

Description: Numbers followed by the same letter in the same treatment indicate no significant difference in the 5% BNJ test; tn = no considerable effect.

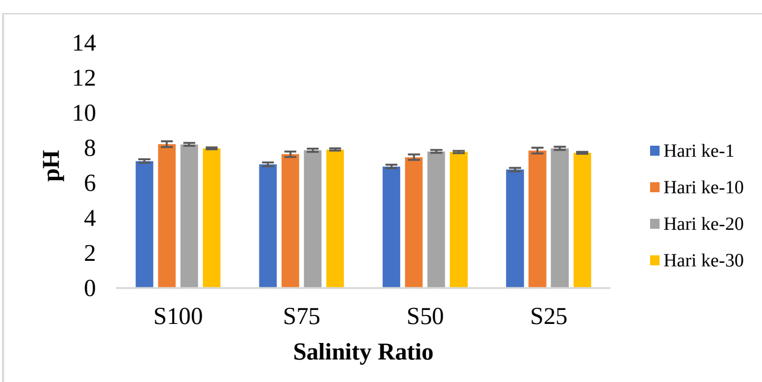

Figure 3. Graph of average pH value of Drainage Water for 30 days

During this period, drainage functions as a filtering agent that helps maintain the balance of ions in the soil. Saline soil is soil with a high concentration of salt minerals (Muharam & Saefudin, 2016). Several problems arise, so saline soil is rarely used for plant cultivation, including low plant osmotic pressure, low N and K elements, high Na^+ content, and high soil pH (Rahman et al., 2025). Excess salt washing with irrigation can be done in saturated water conditions using rainfall or fresh water from rivers to make saline soil arable. One way to accelerate salt washing is to build a drainage system (Muharam & Saefudin, 2016).

The pH values for all treatments tended to be stable, with a slight decrease on days 20 and 30 compared to day 10. The 5% BNJ test revealed that days 1 and 10 showed significant differences between treatments but were unimportant on days 20 and 30. This point indicates that after 20 days, underground drainage successfully reduced the effect of salinity and equalized the pH values in all treatments.

The stability of the pH value indicates that the drainage system has reached a balance in reducing soil salinity. This point is in line with the concept of alkalinity, which is defined as the ability of a system to maintain balance against changes in acidity (pH) (Supwatul Hakim et al., 2023). High pH results in a lack of nutrients characterized by stunted and yellowing or dark green to purplish plants (Muharam & Saefudin, 2016). These results indicate that although the initial salinity levels are different, the effectiveness of drainage in improving soil pH remains consistent. With a pH value approaching neutral at the end of the observation, soil conditions become more supportive of plant growth.

3.2. EC Value of Drainage Water

Electrical conductivity (EC) measurements of drainage water were conducted to evaluate the effectiveness of underground drainage methods in reducing soil salinity. The results of EC measurements of drainage water at various ratios of saline and non-saline soil mixtures are presented in Table 2.

Table 2. Average results of EC measurements of Drainage Water

Treatment	Average EC Day 2 ($dS.m^{-1}$)			
	1	10	20	30
S100	8.90 ± 0.29 c	2.03 ± 0.25 b	1.00 ± 0.1	0.93 ± 0.12 bc
S75	6.42 ± 1.4 ab	2.30 ± 0.57 b	1.04 ± 0.11	0.83 ± 0.11 b
S50	5.99 ± 0.36 a	2.89 ± 0.44 c	1.22 ± 0.5	0.94 ± 0.13 bc
S25	6.82 ± 1.19 ab	1.18 ± 0.06 a	0.74 ± 0.07	0.60 ± 0.03 a
BNJ 5%	1.10	0.45	tn	0.12

Description: Numbers followed by the same letter in the same treatment indicate no significant difference in the 5% BNJ test; tn = no significant effect.

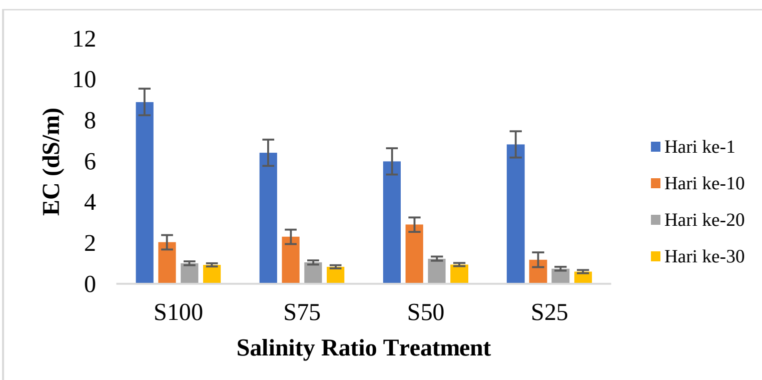

Figure 4. Graph of average EC values of Drainage Water for 30 days.

The results of the data displayed in Table 2 and the EC value trend graph show that the electrical conductivity (EC) value experienced a significant decrease during the 30 days of observation. This decrease indicates that the underground drainage system effectively reduces salt levels in the soil.

On the first day, the highest EC value was found in the S100 treatment (8.90 dS/m), followed by S25 (6.82 dS/m), S75 (6.42 dS/m), and S50 (5.99 dS/m). This difference reflects that the higher the ratio of saline soil in the mixture, the higher the measured EC value.

After 10 days, the EC value decreased drastically in all treatments. This significant decrease indicates that salt leaching through underground drainage began to work effectively in reducing salinity. This drastic decrease indicates that salt ions such as Na^+ and Cl^- have been significantly reduced due to the leaching process by the drainage system (Muharam & Saefudin, 2016). The higher the salt concentration is, the electrical conductivity of the soil test sample (EC) will increase (Nasyirah et al. 2015). The decrease in the EC value became slower and more stable from the 10th to the 30th day. According to

(Elfarisna, 2018), salinity will affect the physical and chemical properties of the soil, namely increased osmotic pressure, increased ionization potential, poor soil infiltration, disturbed soil structure, poor soil permeability and decreased conductivity. This stability reflects that the balance between salt ions and water in the soil has been achieved, and the drainage system is functioning optimally in maintaining these conditions. The S50 treatment experienced the greatest decrease in EC compared to other treatments, from 5.99 dS/m to 2.89 dS/m.

The average results on the 20th and 30th days showed that the EC values continued to decrease to approach lower and stable values. There was no significant difference between treatments on the 20th and 30th days, as indicated by the 5% BNJ test results, which stated "tn" (no significant effect). On the 30th day, the EC values in all treatments ranged from 0.60–0.94 dS/m, indicating that most of the salt had been flushed out through the underground drainage system. Although there were significant differences between treatments initially, these differences became smaller over time, indicating that underground drainage successfully reduced salinity levels evenly, regardless of the initial soil composition. (Muharam & Saefudin, 2016).

3.3. TDS Value of Drainage Water

Total Dissolved Solids (TDS) measurement in drainage water is carried out to indicate the content of dissolved substances carried out of the soil during the salt washing process. The results of measuring the TDS value of drainage water at various ratios of saline and non-saline soil mixtures are presented in Table 3.

Table 3. Average results of TDS measurements of Drainage Water

Treatment	Average TDS Day- (ppm)			
	1	10	20	30
S100	4440.33 ± 128.88 c	1034.67 ± 100.9 b	502.33 ± 49.9	462.67 ± 58.71 bc
S75	3361.67 ± 538.14 ab	1157 ± 300.98 b	522.33 ± 52.7	413.67 ± 56.62 b
S50	3000.34 ± 195.99 a	1415.67 ± 247.01 c	610.33 ± 249.97	468.67 ± 62.92 c
S25	3313.34 ± 613.11 ab	581 ± 37 a	367.33 ± 36.02	297.33 ± 13.65 a
BNJ 5%	494.97	235.54	tn	60,60

Description: Numbers followed by the same letter in the same treatment indicate no significant difference in the 5% BNJ test; tn = no considerable effect

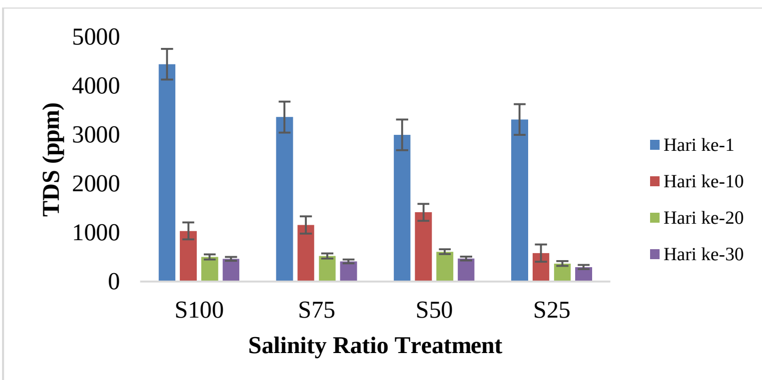

Figure 5. Graph of average TDS values of water drainage over 30 days.

Based on the results shown in Table 4.3 and the TDS value trend graph, it can be seen that Total Dissolved Solids (TDS) experienced a significant decrease during 30 days of observation in all treatments. This decrease indicates that the underground drainage system effectively reduces the dissolved salt content in the soil.

The average TDS value on the first day was highest in the S100 treatment (4440.33 ppm), followed by S75 (3361.67 ppm), S25 (3313.34 ppm), and S50 (3000.34 ppm). This highlight shows that the higher the ratio of saline soil in the mixture, the higher the solute content.

After 10 days, there was a drastic decrease in all treatments. The TDS value for the S100 treatment decreased to 1034.67 ppm, while the other treatments also experienced a significant decline. This decrease indicates that salt leaching through underground drainage occurred effectively in the first 10 days.

The average results on the 20th and 30th days showed that the TDS value continued to decrease but at a slower rate than the first 10 days. On the 30th day, the TDS value for all treatments ranged from 297.33–468.67 ppm, indicating that most dissolved salts had been flushed through the underground drainage system. This point shows the effectiveness of the underground drainage system in reducing the content of dissolved ions in the soil. This decrease in TDS indicates that the underground drainage system can remove cations and anions that cause salinity to dissolve in the soil (Sutrisno et al., 2020).

The results of the 5% BNJ test showed that there were significant differences between treatments on the 1st and

10th days, but on the 20th and 30th days, the differences were not substantial (tn). This point indicates that after 20 days, underground drainage has succeeded in equalizing TDS levels in all treatments. This stability suggests that the soil has reached a balance in reducing salt content, thereby increasing soil fertility for plant growth (Nasyirah et al., 2015).

The final results of the observation showed a low TDS value; according to (Rinawati et al., 2016), a low TDS level indicates the presence of few organic and inorganic compounds, minerals, and salts dissolved in water. In contrast, high TDS values in seawater are caused by high chemical compound content, which also contributes to high salinity and electrical conductivity. Therefore, the TDS value in all treatments ranged from 200–500 ppm, indicating a low level of dissolved salt compounds and supporting the soil's suitability for plant growth. Although there was a significant difference at the beginning of the observation between treatments with different saline soil concentrations, the difference became insignificant at the end.

These three parameters are interrelated in indicating the success of soil salinity management. The stability of pH accompanied by a decrease in EC and TDS suggests that the underground drainage system reduces the dissolved salt content and improves the soil's overall chemical properties. As stated by (Sodik Imanudin et al., 2016), underground drainage has been proven to reduce pollution, decreasing nitrate leaching. Treatments with high initial salinity levels (S100) took longer to reach stability than treatments with lower salinity levels (S25). Still, at the end of the observation, the results were almost the same in all treatments. This point shows that the drainage system can be used for various initial saline soil conditions.

3.4. Soil pH and EC Values

Soil pH measurement was conducted to determine changes in soil acidity levels after being treated with underground drainage and salt leaching. Soil electrical conductivity (EC) values were measured to see how soil salinity changed due to underground drainage treatment.

Table 4. Average results of soil pH measurements

Treatment	Soil pH value on day 2			
	0	10	20	30
S100	7.56 ± 0.08	7.90 ± 0.01 s	8.15 ± 0.08 c	7.94 ± 0.14
S75	7.18 ± 0.13	7.46 ± 0.17 b	7.84 ± 0.12 ab	7.76 ± 012
S50	7.1 ± 0.07	7.26 ± 0.07 a	7.64 ± 0.25 a	7.73 ± 0.18
S25	7.28 ± 0.15	7.68 ± 0.16 c	7.86 ± 0.2 b	7.64 ± 0.15
BNJ 5%	-	0.14	0.20	tn

Description: Numbers followed by the same letter in the same treatment indicate no significant difference in the 5% BNJ test; tn = no considerable effect.

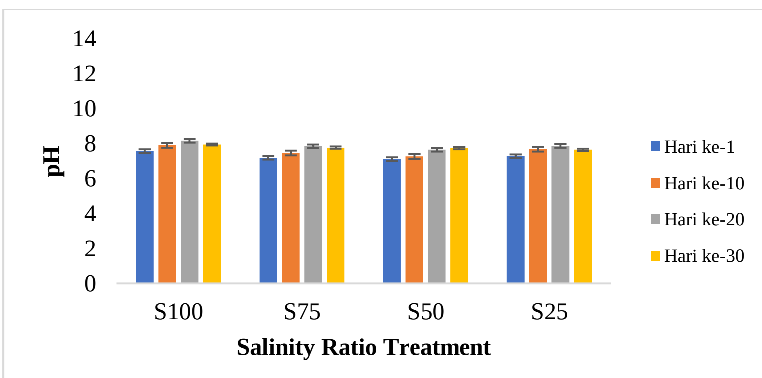

Figure 6. Graph of average soil pH values for 30 days

The results of soil pH measurements showed variations based on treatment and observation time. On the 10th day, the S100 treatment gave the highest pH of 7.90, significantly different from other treatments, while the S50 treatment had the lowest pH of 7.26. The high pH in the S100 treatment indicates that saline soil has a high concentration of salt minerals in its initial condition, resulting in a higher pH value (Muharam & Saefudin, 2016).

On the 20th day, the pH of the soil in the S100 treatment remained the highest, which was 8.15, significantly different from the other treatments, while the pH of the S75 and S25 treatments were not significantly different. This point indicates that the high salinity level in the S100 treatment caused a significant increase in soil pH (Nasyirah et al., 2015).

On the 30th day, the pH values between treatments did not show a significant difference (tn), with a pH value range between 7.64 and 7.94. These results indicate that the salinity level in the first 10 days affected the soil pH in the initial observations. Still, the effect decreased over time, possibly due to the soil washing process stabilizing the soil pH value. The stability of this pH value indicates that the salt-washing process has effectively reduced the salt content in the soil so that the pH value becomes more stable (Muharam & Saefudin, 2016). This decrease in pH is essential to reduce damage to soil structure and increase soil fertility (Soekamto & Fahrizal, 2019).

Table 5. Average results of soil EC measurements

Treatment	Day-to-day soil EC value (dS.m $^{-1}$)			
	0	10	20	30
S100	8.83 ± 0.23	5.40 ± 0.32 c	1.34 ± 0.1 b	0.95 ± 0.13
S75	7.49 ± 0.24	4.72 ± 0.74 b	1.36 ± 0.1 b	0.89 ± 0.13
S50	6.65 ± 0.36	4.73 ± 0.3 b	1.90 ± 0.71 c	1.00 ± 027
S25	6.99 ± 0.24	3.27 ± 0.38 a	0.91 ± 0.06 a	0.62 ± 0.01
BNJ 5%	-	0.54	0.42	tn

Description: Numbers followed by the same letter in the same treatment indicate no significant difference in the 5% BNJ test; tn = no considerable effect

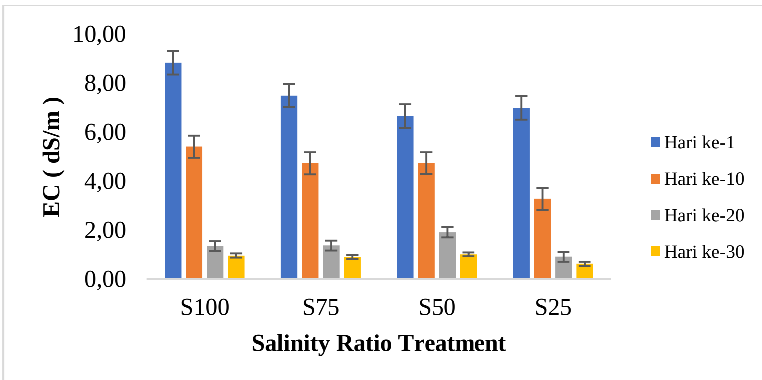

Figure 7. Graph of average EC value of soil for 30 days

The results of soil EC measurements showed variations between treatments and observation times. On the 10th day, the S100 treatment had the highest EC value of 5403 µS/cm, significantly different from other treatments, while S25 showed the lowest EC value of 3276 µS/cm. This point indicates that saline soil initially has a high concentration of salt minerals, which results in a higher EC value (Muharam & Saefudin, 2016).

On the 20th day, the EC value of the soil in the S50 treatment was the highest, with a value of 1907 µS/cm, followed by S100 and S75, which were not significantly different (1344a and 1368a µS/cm, respectively) presumably because both treatments had high concentrations and leaching rates that tended to start to stabilize. The S25 treatment still had the lowest EC value of 911 µS/cm. This shows that the high salinity level in the S50 treatment caused a significant increase in soil EC in the early leaching stages. (Nasyirah et al., 2015) .

On the 30th day, the difference in EC values between treatments did not show a significant difference (tn), with a range of values between 626 to 1006 µS/cm. These results indicate that the salinity level in the first 10 days affected the soil EC value in the initial observation. Still, the effect tended to decrease over time due to the soil washing process through underground drainage. This decrease in EC value is essential to increase soil fertility because high salinity will damage the soil structure and reduce its productivity (Muharam & Saefudin, 2016).

3.5. Sodium Content in Soil

Sodium content in soil was measured to determine how much sodium ions were reduced after underground drainage and salt leaching treatment. The results of exchangeable sodium analysis at various ratios of saline and non-saline soil mixtures are presented in Table 6.

Table 6 shows the results of the measurement of sodium cations (Na-dd), electrical conductivity (EC), and classification of soil salinity criteria in various treatments and observation times. On day 1 (without drainage), all treatments from S25 to S100 showed high EC values, ranging from 6.6 to 8.8 dS/m, and Na-dd% values between 25% and 30%. Based on the salinity and sodicity criteria, all samples on day 1 were included in the very high category, indicating salinity and sodium levels that have the potential to interfere with plant growth. On the other hand, after 30 days of treatment (with drainage), there was a decrease in both Na-dd and EC content. The EC value dropped to a range of 0.6 to 1.0 dS/m, and Na-dd% dropped to below 4%, even as low as 0.7%. This shows that the 30-day treatment reduces salinity and exchangeable sodium content in the soil.

All treatments after 30 days were included in the very low category, indicating that the soil conditions were safer for plant growth. This decrease suggests that the salt-leaching process through underground drainage effectively reduces sodium levels in the soil. This aligns with research (Muharam & Saefudin, 2016), which states that excessive salt leaching with irrigation can be carried out in water-saturated conditions using rainfall or fresh water from rivers and can be accelerated by building a drainage system. This system accelerates water flow from the land to the quaternary and tertiary channels (Sodik Imanudin et al., 2016).

Table 6. Measurement results of Sodium Cation Criteria, Electrical Conductivity and Exchangeable Sodium.

Treatment (day)	Na cmol.kg $^{-1}$	EC dS.m $^{-1}$	Na-dd %	Criteria
S100 (1)	6.5	8.8	26	very high
S75 (1)	6.3	7.4	25	very high
S50 (1)	7.5	6.6	30	very high
S25 (1)	6.2	6.9	25	very high
S100 (30)	0.3	0.9	1.3	very low
S75 (30)	0.5	0.8	2	very low
S50 (30)	0.9	1	3.8	very low
S25 (30)	0.1	0.6	0.7	very low

The efficiency of salt leaching through underground drainage can be analyzed based on the difference between the initial and final values of Na-dd content. Treatment S50 had the highest initial sodium content, which was 7.50 cmol.kg^{-1}, and after 30 days, it decreased to 0.96 cmol.kg^{-1}. This highlight shows that underground drainage can remove most of the sodium, although it remains in higher amounts than other treatments. Treatment S25 showed the best results in sodium leaching, with a decrease from 6.29 cmol.kg^{-1} to 0.18 cmol.kg^{-1}, indicating that leaching is optimal at lower salinity levels.

The effect of sodium leaching through underground drainage is closely related to the initial salinity level. Treatments with higher salinity, such as S50 and S100, still leave more sodium than treatments with lower salinity, such as S25. This point may be due to a threshold of drainage effectiveness in removing sodium from the soil, where the higher the initial sodium content, the more difficult it is for the drainage system to completely remove the content within 30 days.

3.6. Impact of Salinity Changes on Spinach Growth

The results of the observations showed an impact of salinity levels on spinach growth as measured by plant height, root length, and number of leaves. Based on the results of the BNJ test in Table 7. there are significant differences in the growth of spinach plants after 30 days of treatment, including plant height, root length, number of leaves, and leaf width. Treatment S25 (a mixture of soil with 25% saline soil and 75% non-saline soil) produced the most optimal growth with a plant height reaching 35.6 cm, a root length of 14.33 cm, several leaves of 13.33 strands, and a leaf width of 5.67 cm. This value indicates that low salinity provides an ideal environment for spinach growth. Soil with low salinity contains fewer inorganic compounds, so it does not interfere with the process of water and nutrient absorption by plants (Muharam and Saefudin. 2016). The results of treatment S50 (50% saline soil and 50% non-saline soil) were slightly lower than in S25. Plant height reached 33.67 cm, root length 11.33 cm, number of leaves 11 strands, and leaf width 5 cm. However, these results are still better than treatments with higher salinity.

As seen in Figure 7, there is a significant difference in spinach plant growth between salinity treatments. Spinach plants in the S25 treatment (25% saline soil) appear to have the most optimal growth with taller stems and wider leaves compared to other treatments. In the S50 treatment, the plants still showed quite good growth, although slightly lower than S25. The S75 treatment began to show growth inhibition, with shorter plant heights and fewer leaves. Meanwhile, in the S100 treatment (100% saline soil), the plants showed the lowest growth, with short stems and leaves that looked pale and smaller. This highlight shows that higher salinity levels harm spinach plant growth.

The effect of salinity stress on plant growth has also been reported in various previous studies. Anugrahtama. et al. (2020) stated that salinity stress can impact plant agronomic characteristics, including plant height. High salinity causes osmotic stress, inhibiting water absorption and disrupting cell division and enlargement (Romadloni et al., 2018). In addition, the high concentration of Na^+ ions in saline soil reduces the availability of essential elements such as Ca, Mg, and K, which are very much needed by plants for optimal growth (Wahyuningsih et al., 2017). As a result, plants experience a decrease in height, reduced leaf area, and disruption in the photosynthesis process caused by the toxicity of sodium and chloride ions. These disturbances contribute to low production and biomass yields of plants exposed to high salinity. This point shows that spinach with higher saline soil treatment experienced decreased growth compared to treatments using more non-saline soil mixtures.

Figure 8 shows the differences in the morphology of spinach plant roots in various salinity treatments after 30 days of planting (DAP). Spinach plants planted in the S25 treatment (25% saline soil) showed the best root development with a root length of 13 cm and more root branching compared to other treatments. In the S50 treatment, the root length was still relatively good even though there was a reduction in root length and branching with a root length of 11 cm. Meanwhile, plants in the S75 and S100 treatments showed shorter root lengths with very few branches with lengths of 7 cm and 8 cm. In the S100 treatment, the roots appeared the smallest, shortest, and had minimal branching. This point shows that the higher the salinity levels in the planting medium, the more inhibited the growth of spinach plant roots.

Table 7. Average plant height, root length, number of leaves, and leaf width on the 30th day.

Treatment	Parameter			
	Plant height (cm)	**Root length (cm)**	**Number of leaves**	**Leaf width (cm)**
S100	20.97 ± 1.27 a	8.87 ± 1.65	9.34 ± 1.15 ab	2.84 ± 0.76 a
S75	27.97 ± 7.87 b	10.24 ± 2.54	8.67 ± 1.15 a	3.84 ± 0.29 b
S50	33.67 ± 1.15 c	11.00 ± 2.65	10.34 ± 0.58 ab	5.00 ± 0.5 c
S25	35.60 ± 5.5 c	14.34 ± 2.31	13.34 ± 3.06 c	5.67 ± 0.58 d
BNJ 5%	5.68	tn	2.05	0.65

Description: Numbers followed by the same letter in the same treatment indicate no significant difference in the 5% BNJ test; tn = no considerable effect

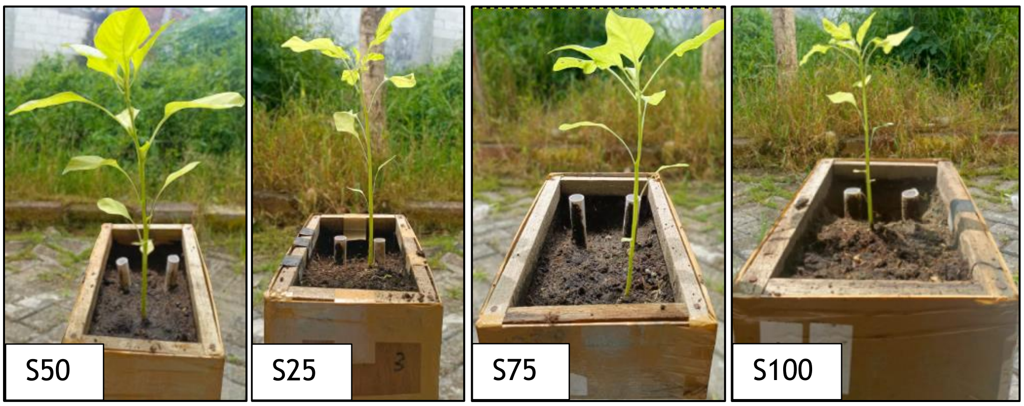

Figure 8. Spinach Plants S25, S50, S75, S100 30 Days After Planting

Figure 9. Spinach Plant Roots S100, S75, S50, S25 30 Days After Planting

These results are in line with research stating that the growth of plant roots and crowns depends on the adequacy of water and nutrients, but excessive NaCl content in the soil can increase osmotic pressure in the soil solution, thereby inhibiting the ability of roots to absorb water (Anugrahtama et al. 2020). In addition, the higher the concentration of NaCl in the soil, the lower the average root length produced (Ester et al., 2019). This point occurs because increased osmotic pressure due to high salinity can inhibit optimal root development (Anugrahtama et al., 2020).

According to (Kusumiyati et al., 2018) . NaCl poisoning also affects root length because root meristem cells are susceptible to the presence of mineral salts. This disorder disrupts the mitosis division process, essential in supporting root growth. However, some plants have adaptive mechanisms to maintain water conditions in their bodies, one of which is through root elongation to preserve the sustainability of physiological processes (Anugrahtama et al., 2020). Thus, high salinity can suppress the growth of spinach roots, while soil conditions with lower salinity allow for more optimal root development.

Overall, it indicates that increasing salinity in soil harms spinach growth while reducing saline soil levels by mixing non-saline soil can significantly improve plant growth. Saline soil with higher concentrations disrupts water and nutrient absorption by plants, thus inhibiting overall growth (Muharam & Saefudin, 2016).

Treatment S75 (75% saline soil and 25% non-saline soil) significantly decreased all parameters. Plant height only reached 27.97 cm, root length 10.23 cm, number of leaves 8.67, and leaf width 2.83 cm. This highlight indicates that higher salinity begins to put pressure on plant growth. High salinity levels will damage soil structure, reduce productivity, and kill soil-fertilizing organisms (Muharam & Saefudin, 2016).

Treatment S100 (100% saline soil) showed the lowest growth with a plant height of 20.97 cm, root length of 8.87 cm, number of leaves of 9.33, and leaf width of 2.83 cm. High salinity disrupts plants' absorption of water and nutrients, thereby inhibiting overall growth. The soil's salinity problem causes increased osmotic pressure, ionization potential, and disruption of soil structure (Junandi et al., 2019). Based on the 5% BNJ test, significant differences were seen in plant height, number of leaves, and leaf width, while root length did not show a significant effect between treatments. This point indicates that the salt leaching process through underground drainage has reduced soil salinity levels, thereby increasing spinach plant growth (Muharam & Saefudin, 2016).

4. Conclusion

Based on the research results, it can be concluded that

1. Underground drainage can reduce soil salinity, indicated by a decrease in water pH after the 20th day, a decrease in EC from 8.90 dS/m to around 1 dS/m, and a decrease in TDS from 4440.33 ppm to 462.67 ppm.
2. Sodium and Na-dd levels decreased significantly after treatment, from 6.2–7.5 $cmol.kg^{-1}$ to 0.1 – 0.9 $cmol.kg^{-1}$, and from 23% – 30% to 0.7% – 3.8%, indicating successful leaching of sodium ions from the soil.
3. The decrease in salinity has a positive impact on the growth of spinach, with the 25% saline soil mixture treatment (S25) producing the best growth (height 35.60 cm, root length 14.34 cm, number of leaves 13.34 strands, and larger leaf width) compared to high salinity treatments such as S100.

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References

Anugrahtama, P. C., Supriyanta, S., & Taryono, T. (2020). Pembentukan bintil akar dan ketahanan beberapa aksesi kacang hijau (*Vigna radiata* L.) pada kondisi salin. *Agrotechnology Innovation (Agrinova), 3*(1), 20. https://doi.org/10.22146/a.58353

Elfarisna. (2018). Pemikiran untuk keberlanjutan pertanian. *Angewandte Chemie International Edition, 6*(11), 951–952.

Ester, G., Karuniawan, & Wicaksono, P. (2019). Respon 3 varietas pakcoy (*Brassica rapa* L.) terhadap simulasi cekaman salinitas. *Jurnal Produksi Tanaman, 7*(6), 1107–1114.

Junandi, J., Mukarlina, M., & Linda, R. (2019). Pengaruh cekaman salinitas garam NaCl terhadap pertumbuhan kacang tunggak (*Vigna unguiculata* L. Walp) pada tanah gambut. *Jurnal Protobiont, 8*(3), 101–105. https://doi.org/10.26418/protobiont.v8i3.36869

Karamina, H., Fikrinda, W., & Murti, A. T. (2018). Kompleksitas pengaruh temperatur dan kelembaban tanah terhadap nilai pH tanah di perkebunan jambu biji varietas kristal (*Psidium guajava* L.) Bumiaji, Kota Batu. *Kultivasi, 16*(3), 430–434. https://doi.org/10.24198/kultivasi.v16i3.13225

Khumairo, G. A., & Handayani, B. L. (2022). Habitus masyarakat di daerah kekeringan pada Desa Jatisari Kabupaten Situbondo. *Journal of Urban Sociology, 5*(1), 59. https://doi.org/10.30742/jus.v5i1.2050

Kusumiyati, K., Farida, F., Sutari, W., & Mubarok, S. (2018). Mutu buah sawo selama periode simpan berbeda. *Kultivasi, 16*(3), 451–455. https://doi.org/10.24198/kultivasi.v16i3.14385

Muharam, & Saefudin, A. (2016). Pengaruh berbagai pembenah tanah terhadap pertumbuhan dan populasi tanaman padi sawah (*Oryza sativa* L.) varietas Dendang di tanah salin sawah bukaan baru. *Jurnal Agrotek Indonesia, 469*(3), 319–323. https://doi.org/10.7868/S0869565216210155

Nasyirah, N., Kalsim, D., & Saptomo, S. (2015). Analysis of the rate of saline soil leaching by using subsurface drainage. *Jurnal Keteknikan Pertanian, 3*(2), 1-8. https://doi.org/10.19028/jtep.03.2.89-96

Rahman, A., Fachruzi, I., & Syarbini, M. (2025). Penambahan fraksi pasir dan amelioran terhadap sifat fisika dan kimia tanah salin yang sudah dilindi. *Acta Solum, 1*(1), 46–53. https://doi.org/10.20527/actasolum.v3i1.2845

Rinawati, Hidayat, D., Suprianto, R., & Sari Dewi, P. (2016). Penentuan kandungan zat padat (total dissolve solid dan total suspended solid) di perairan Teluk Lampung. *Analit: Analytical and Environmental Chemistry, 1*(1), 36–46. http://jurnal.fmipa.unila.ac.id/analit/article/view/1236/979

Romadloni, A., Karuniawan, D., & Wicaksono, P. (2018). Pengaruh beberapa level salinitas terhadap perkecambahan kacang hijau (*Vigna radiata* L.) varietas Vima 1. *Jurnal Produksi Tanaman, 6*(8), 1663–1670.

Sodik Imanudin, M., Bakri, B., & Tambunan, A. (2016). Kajian teknik aplikasi drainase bawah tanah dengan menggunakan bahan baku lokal. *Planta Tropika: Journal of Agro Science, 4*(1), 14–19. https://doi.org/10.18196/pt.2016.051.14-19

Soekamto, M. H., & Fahrizal, A. (2019). Upaya peningkatan kesuburan tanah pada lahan kering di Kelurahan Aimas Distrik Aimas Kabupaten Sorong. *Abdimas: Papua Journal of Community Service, 1*(2), 14–23. https://doi.org/10.33506/pjcs.v1i2.670

Supwatul Hakim, M., Hermayantiningsih, D., Riana Dewi, S., Ayu Andhita, N., & Jhonatan Krissilvio, E. (2023). Analysis of acidity and alkalinity levels in primary drainage canal IV Bukit Keminting, Palangka Raya, Central Kalimantan. *Indonesian Journal of Chemical Research, 8*(1), 57–66.

Sutrisno, J., Kholif, M. Al, & Rohma, A. N. (2020). Penerapan adsorbsi, pertukaran ion, dan variasi kualitas air sumur gali. *Jurnal Sains dan Teknologi, 19*(2), 69–75.

Wahyuningsih, S., Kristiono, A., & Taufiq, A. (2017). Pengaruh ameliorasi tanah salin terhadap pertumbuhan dan hasil kacang hijau. *Buletin Palawija, 15*(2), 69. https://doi.org/10.21082/bulpa.v15n2.2017.p69-77