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Evaluating soil salinity and its impact on agricultural crop productivity (wheat as a model)

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Abstract

This research aims to achieve a set of scientific and applied objectives, summarized as follows: analyzing soil salinity in terms of its causes and associated chemical and physical properties; evaluating the impact of salinity on the growth stages and productivity of wheat; and studying relatively salt-tolerant wheat varieties under specific environmental conditions. The research yielded the following results:

1. The comparison showed that accurately determining the extent of the problem requires combining several methods. While electrical conductivity (EC) is characterized by accuracy and speed, remote sensing techniques emerge as an ideal option for covering large areas and analyzing them immediately. However, biological monitoring remains the most realistic field tool for measuring the actual plant response.
2. The results demonstrated that wheat begins to be significantly affected when salinity exceeds the threshold of 4 dS/m, at which point a gradual decline in production begins. The risk reaches its peak when salinity ranges between 8 and 12 dS/m, causing significant growth damage, leading to near-complete loss of productivity when the threshold exceeds 12 dS/m.
3. The study revealed genetic variations that offer a glimmer of hope for overcoming this crisis. Varieties such as "Salima" in Morocco, "Experimental 4" in Syria, and "Abu Ghraib 3" in Iraq demonstrated high to moderate tolerance to salinity. The "Sham 6" variety, supported by the ACSAD Center, also emerged as a strategic option for areas with moderate salinity.

Keywords: Wheat, soil salinity, agricultural crops, theoretical foundations, applied foundations

Introduction

Soil is one of the most important elements of the agricultural environment, as it forms the essential incubator for crop growth and food production. However, its chemical and physical properties can undergo changes that negatively affect its productivity. Among the problems that are becoming increasingly acute is soil salinity, a phenomenon that causes a decline in agricultural production and threatens food security, especially in arid and semi-arid regions that rely heavily on irrigation.

Wheat is one of the most important strategic crops whose production is directly affected by high soil salinity, given its moderate sensitivity to salinity. This underscores the importance of studying its impact on this growing phenomenon. The importance of this topic is amplified by the decline in agricultural soil quality, climate change, and increasing food demand, which necessitates the development of effective strategies for assessing and controlling salinity, particularly in lands where cereal crops are grown.

Therefore, this research aims to analyze the causes and consequences of salinity and methods for assessing it, focusing on the physiological and quantitative effects of soil salinity on wheat production, and reviewing possible scientific solutions to address it.

Research Problem

In light of the above, the main problem of this research can be formulated in the following question:

To what extent does soil salinity affect wheat crop productivity, and what are the most effective methods for assessing and controlling it using modern agricultural scientific techniques?

From this main problem, the following sub-questions branch out:

1. What are the causes and sources of soil salinity in agricultural environments?
2. How does the wheat plant respond to salinity at different growth stages?
3. How can salinity be accurately assessed in the field and in the laboratory?
4. What are the most important agricultural and genetic techniques used to mitigate the effects of salinity on wheat production?

First: Research Objectives

This research aims to achieve a set of scientific and applied objectives, summarized as follows:

1. Analyzing soil salinity in terms of its causes and associated chemical and physical properties.
2. Evaluating the impact of salinity on the growth stages and productivity of wheat.
3. Determining the critical salinity thresholds that affect wheat's germination, growth, and yield.
4. Comparing different salinity assessment methods (laboratory, digital, and biological) in terms of accuracy and efficiency.
5. Proposing appropriate agricultural and management techniques to reduce the impact of salinity on wheat production.
6. Studying relatively salt-tolerant wheat varieties under specific environmental conditions.

Second: Research Hypotheses

This research is based on the following hypotheses, which will be verified through theoretical and field analysis:

1. There is a direct relationship between high soil salinity and low wheat productivity.
2. Wheat varieties respond differently to salinity depending on their genetic makeup and adaptability.
3. Using appropriate irrigation and drainage techniques helps reduce the impact of salinity on the soil and plants.
4. Soil salinity can be accurately assessed by combining physical measurements with biological methods.
5. Adding organic matter and agricultural gypsum improves the properties of saline soils and increases production.

Third: Research Limitations

This research is limited by a set of parameters that define its scope and findings, namely:

1. **Subject Matter Limitations:** The research focuses solely on the impact of soil salinity (and not other elements such as acidity or nutrient deficiencies), specifically examining wheat crops.
2. **Spatial Limitations:** The study is based on a literature review and field experiments conducted in arid and semi-arid environments, particularly in agricultural areas with varying salinity levels in Arab countries (such as Iraq, Syria, Morocco, and Egypt).
3. **Temporal Limitations:** The research covers studies published between 2015 and 2026, focusing on the impact of salinity during the winter growing season for wheat, as this is the most common season for this crop.

The worsening phenomenon of soil salinity poses a real threat to sustainable agricultural development. Globally,

more than 800 million hectares are affected by salinity, a significant portion of which are located in wheat-producing regions. The uncontrolled use of poor-quality irrigation water, inadequate drainage systems, and rising temperatures have combined to increase salt accumulation in the upper layers of agricultural soil. Soil salinity affects plants by impacting water and nutrient absorption and disrupting the ionic balance within plant cells, leading to reduced growth, decreased spike formation, reduced grain weight, and consequently, lower overall yield. Given wheat's importance in the human diet, studying the relationship between soil salinity and wheat production is both a scientific and societal imperative, especially in light of climate change and uncontrolled agricultural expansion. Therefore, this research will also address management strategies that can mitigate the negative effects of salinity on this vital crop (Al-Hashemi, 2022, p. 12) ^[9].

Chapter 1: Theoretical and Applied Foundations for Soil Salinity Assessment

Section 1: General Concepts of Soil Salinity

Soil salinity is one of the most prominent problems facing agriculture in arid and semi-arid regions, due to its direct impact on soil fertility, plant nutrient absorption, and consequently, agricultural productivity. The accumulation of salts in the root zone leads to an imbalance in the plant's water content and reduces the roots' ability to absorb water, negatively affecting crop growth and yield.

"This problem has worsened globally in recent decades as a result of the excessive use of poor-quality irrigation water, poor water resource management, rising temperatures, and climate change. This has contributed to an increase in the percentage of land affected by salinity, especially in lands cultivated with strategic crops such as wheat, which is the staple food for the majority of the world's population" (Al-Salem, 2022, p. 134) ^[8]. The importance of this research lies in its attempt to scientifically and systematically evaluate the impact of soil salinity, using analytical tools and physical and chemical parameters, with a focus on wheat as an applied model. The research also examines the physiological mechanisms wheat plants use to adapt to salinity and the most important agricultural strategies to mitigate its effects.

"Salinity affects vital processes within the plant and reduces absorption efficiency, especially during the germination stage, which is the most sensitive to salinity," thus illustrating the severity of this phenomenon for the growth of staple crops like wheat (Mahdi, 2022, p. 22) ^[6]". Soil salinity is defined as the accumulation of dissolved salts in the root zone of the soil to a level that negatively impacts plant growth and productivity, whether these salts are of natural origin or result from human activities such as excessive irrigation or chemical fertilizer use. These salts are often composed of calcium, sodium, magnesium, chlorine, and sulfate compounds, and their severity increases when the electrical conductivity exceeds 4 dS/m in the soil solution, the threshold at which negative effects begin to impact most crops.

Their severity increases when the electrical conductivity exceeds 4 dS/m in the soil solution, which is the threshold at which negative effects begin to affect most crops. Saline soils are classified into three main types: saline soils, alkaline soils, and saline-sodic soils, according to their electrical conductivity (EC), exchangeable sodium ratio (ESP), and sodium adsorption ratio (SAR). These factors

collectively affect soil structure, cohesion, aeration, and water retention capacity.

"Soil salinity is not merely a chemical problem; it is closely linked to the physical, hydrological, and biological properties of the soil. Its danger lies in its gradual, often invisible accumulation, until its severe effects on agricultural production become apparent too late" (Al-Sarhani, 2015, p. 89)) ^[3]. Understanding the characteristics of saline soils is essential for any land reclamation plan or crop selection, especially given the increasing rates of desertification and salinity in many Arab countries due to poor water resource management and climate change, as Al-Jubouri, Mahmoud Abdullah, explained in his study (Al-Jubouri, 2023, p. 56) ^[11].

Section Two: Methods of Measuring and Evaluating Soil Salinity: Soil salinity assessment is a crucial step in understanding the nature of the problem and determining appropriate management methods. Various approaches are used in this context, ranging from field measurements and laboratory analyses to modern remote sensing technologies.

First: Physical and Chemical Measurements.

Salinity levels are typically measured by the electrical conductivity (EC) of the soil solution, which is the primary indicator used to estimate the amount of dissolved salts. Other indicators are also used, such as:

- Sodium Adsorption Ratio (SAR)
- Exchangeable Sodium Percentage (ESP)
- pH

Portable digital analyzers are used to measure EC in the field, while other indicators require precise laboratory testing.

"A comprehensive soil analysis requires sampling at multiple depths, as salt concentration varies with depth and may be high in the lower layers without being noticeable at the surface." (Al-Mahdi, 2010, p. 43) ^[2].

Second: Remote Sensing and Digital Modeling

With the development of satellite and drone technologies, it has become possible to create accurate digital maps of salinity across vast areas of land by analyzing the reflected spectrum of the soil surface at specific wavelengths. The data is then analyzed using mathematical models to precisely determine the salinity level.

In his extensive study on the use of remote sensing technologies in Iraq, Musa, Ahmed Jassim (alive at the time of publication) argues that this technology has significantly contributed to identifying areas of saline soil with greater accuracy than traditional methods, especially when combined with moisture and vegetation cover data (Musa, 2022, p. 121) ^[5].

Third: Agricultural and Biological Assessment

Plant growth itself is sometimes used as an indicator of soil salinity by studying germination rates, growth, and biomass formation in crops known to be tolerant or sensitive to salinity. Such as proline and glycine betaine, to maintain osmotic balance. Wheat is a prime example, being a strategic crop that is relatively sensitive to salinity.

Al-Jubouri, Mahmoud Abdullah, reiterated in his book that biological assessment using different wheat varieties is an effective tool for identifying dangerous levels of salinity,

especially when combined with chemical indicators (Al-Jubouri, 2023, p. 25) ^[11].

Chapter Two: The Effect of Soil Salinity on Wheat Productivity

Section One: Wheat's Response to Salinity

Wheat is one of the world's most important food crops, with more than half the world's population relying on it as a primary source of carbohydrates. Despite its widespread cultivation, however, it is considered a crop with moderate salt tolerance. Negative effects of salinity on its growth begin at an electrical conductivity level exceeding 6 dS/m, and yields can decrease by up to 50% at a salinity level of 12 dS/m, according to several researchers.

First: The effect of salinity on the growth stages of wheat

- **Germination stage:** Directly affected by increased soil osmotic tension, which hinders water absorption and delays or prevents germination.
- **Vegetative growth stage:** Salts impair nutrient absorption, especially potassium and calcium, leading to yellowing of leaves and reduced branching.
- **Flowering and fruiting stage:** The most affected stage, as salinity reduces the number of spikes, grain weight, and grain filling percentage.

"Salinity disrupts the ionic balance within plant cells, leading to a disturbance in vital processes such as photosynthesis, respiration, and protein synthesis, which are crucial for normal wheat growth" (Al-Hassani, 2017, p. 154) ^[12].

Second: Physiological Mechanisms for Adapting to Salinity

Wheat possesses several mechanisms that help it adapt to saline soils, including:

- **Regulating ion absorption:** such as reducing sodium absorption and increasing potassium absorption.
- **Accumulating organic osmolytes:** such as proline and glycine betaine, to maintain osmotic balance within cells.
- **Increasing the activity of antioxidant enzymes:** To reduce oxidative damage resulting from salt stress.

Al-Jubouri, Mahmoud Abdullah, confirmed that "the genetic variation of wheat varieties plays a significant role in the plant's response to salinity, as there are local and international varieties that have shown higher efficiency in nutrient uptake under high salinity conditions" (Al-Jubouri, M., 2023, p. 45) ^[11].

Third: Varieties in Salt Tolerance

Multiple field trials have shown that varieties differ in their degree of tolerance. Some varieties, such as Salima and Ruba, have demonstrated relatively stable production even under moderate salinity levels. This is attributed to these varieties' ability to limit sodium accumulation in the leaves, as noted by Musa, Ahmed Jassim in his study.

Section Two: Management Techniques to Improve Wheat Production in Saline Soils: With the increasing area of land affected by salinity in the Arab world and Mediterranean countries, it has become essential to implement agricultural strategies and scientific techniques to

mitigate the negative effects of salinity on wheat production. This study reviews the most prominent of these techniques, which can be categorized into four main areas:

First: Integrated Irrigation and Drainage Management

Controlling the quality and quantity of irrigation water is one of the most effective methods for combating salinity. Excessive irrigation with saline water leads to salt accumulation in the root zone. Therefore:

It is recommended to use temporary flood irrigation followed by good drainage to flush salts from the upper layers.

It is also preferable to apply leaching water at the end of the growing season.

Al-Sharhan, Abdul Aziz Muhammad, indicated that "controlling the timing and quantity of irrigation and providing effective drainage to dispose of excess irrigation water is the first line of defense against soil salinity" (Al-Sharhan, 2016, p. 67) ^[14].

Second: Improving Soil Properties (Chemical and Organic Remediation)

Materials are used to improve the properties of salinity-affected soils, including:

- **Agricultural gypsum (calcium sulfate):** To improve soil structure and reduce exchangeable sodium.
- **Organic matter and compost:** To improve soil permeability and increase microbial activity.
- **Agricultural sulfur:** To adjust pH and improve nutrient absorption. Al-Jubouri, Mahmoud Abdullah, explained that "adding agricultural gypsum and organic materials to the soil gave tangible results in reducing salinity and improving wheat productivity in experiments carried out in southern Iraq" (Al-Jubouri M., 2023, p. 87) ^[11].

Third: Using Resistant Genetic Varieties

Searching for salt-tolerant genetic varieties is one of the most effective long-term strategies. Varieties such as Abu

Ghraib 3 and Shamam have shown positive results under moderate salinity conditions.

Al-Hashemi, Kadhim Abdul-Hussein, stated that "local genetic selection programs that rely on adaptation to saline environments are the real hope for improving production without relying on radical changes to the agricultural system" (Al-Hashemi, 2022, p. 61) ^[9].

Fourth: Use Fertilizers and Micronutrients with Caution

- Potassium and calcium help mitigate the damaging effects of sodium within the plant.
- Zinc and manganese are important for improving photosynthesis in saline environments.

In a study conducted between 2020 and 2022, Musa, Ahmed Jassim, documented that "the balanced addition of micronutrients and macronutrients helped increase wheat's resistance to salinity and raised grain yield by more than 20%" (Al-Hashemi, 2022, p. 83) ^[9].

The challenges posed by soil salinity to wheat productivity necessitate the implementation of a comprehensive set of solutions, including water management, smart fertilization, soil improvement, and the use of suitable genetic varieties. Relying on a single solution alone is insufficient; rather, continuous agricultural and technological integration is required to address this escalating phenomenon. The challenges posed by soil salinity to wheat productivity necessitate the implementation of a comprehensive set of solutions, including water management, smart fertilization, soil improvement, and the use of suitable genetic varieties. Relying on a single solution alone is insufficient; rather, continuous agricultural and technological integration is required to address this escalating phenomenon. The challenges posed by soil salinity to wheat productivity necessitate the implementation of a comprehensive set of solutions, including water management, smart fertilization, soil improvement, and the use of suitable genetic varieties. Relying on a single solution alone is insufficient; rather, continuous agricultural and technological integration is required to address this escalating phenomenon.

Table 1: Comparison table between methods for assessing soil salinity

The method	Its type	The indicator used	Its features	Its disadvantages
Electrical conductivity (EC)	Laboratory	EC (dS/m)	Fast, accurate, available	Equipment required
Sodium absorption rate (SAR)	Chemical	SAR	Reflects the effect of sodium on soil structure	Advanced analysis is needed
remote sensing	Digital	Spectral images	It covers large areas, instant analysis	You need software and analysis
Biological monitoring	agricultural	plant growth	Operational and field	Inaccurate without supporting measurement

Table 2: Soil salinity levels and their effect on wheat production

Salinity level (EC)	Salinity level	Effect on wheat
0 - 2 dS/m	Very low	No negative impact
2 - 4 dS/m	Low	natural production
4 - 6 dS/m	Medium	A slight decrease in production
6 - 8 dS/m	High	A significant decrease in production
8 - 12 dS/m	Very high	Significant damage to growth and production
>12 dS/m	Highly salty	Almost no productivity

Table 3: Wheat varieties that are most tolerant to salt (according to Iraqi and Arab studies)

Category	Tolerance	Source
Abu Ghraib 3	Medium - High	Iraq
Experimental 4	High	Syria
melon	Medium	Iraq
Ruby	Medium	Tunisia
Salima	High	Morocco
Sham 6	Medium	The Arab Center (ACSAD)

Conclusion

Soil salinity represents one of the most serious challenges facing the agricultural sector in the 21st century, particularly in arid and semi-arid environments heavily reliant on irrigation. This study, which assessed soil salinity and its impact on wheat productivity, demonstrated that the relationship between soil and plants is sensitive and complex, influenced by intertwined physical, chemical, and physiological factors.

Throughout the research, it was shown that salinity affects plant life processes from germination to harvest, leading to a significant decrease in growth rates and productivity. Furthermore, the results of previous studies and the data used in this research indicate that wheat is classified as a moderately salt-tolerant crop. Therefore, any abnormal increase in soil salinity levels can have significant effects, especially if soil and irrigation management is not carried out scientifically and meticulously.

The research explored methods for measuring and evaluating salinity, ranging from laboratory analyses (such as electrical conductivity and sodium uptake) to the use of remote sensing techniques, culminating in biological assessment through the plant's own response. This diversity of measurement methods reflects the importance of accurately determining the scale of the problem, especially when preparing agricultural maps and future production strategies.

On the management side, the study highlighted the importance of integrated solutions rather than relying on a single method. Addressing soil salinity requires interventions at multiple levels: modifying soil properties, regulating irrigation and drainage, using resistant varieties, and improving nutrient management.

Soil salinity represents one of the most serious challenges facing the agricultural sector in the 21st century. The study demonstrated that the relationship between soil and plants is complex, influenced by intertwined physical, chemical, and physiological factors. Based on the analysis of the data presented in the appendices, the following conclusions can be drawn:

- 1. Evaluation of Measurement Methods (Table 1 Results):** The comparison showed that accurately determining the scale of the problem requires combining several methods. While electrical conductivity (EC) is characterized by accuracy and speed, remote sensing techniques emerge as an ideal option for covering large areas and analyzing them in real time. However, biological monitoring remains the most realistic field tool for measuring the actual plant response.
- 2. Salinity Thresholds and Wheat Sensitivity (Table 2 Results):** The results showed that wheat yield begins to be affected when salinity exceeds the threshold of 4 dS/m, at which point a gradual decrease in production begins. The risk reaches its peak when salinity ranges between 8-12 dS/m, causing significant growth damage,

leading to near-complete loss of productivity when the threshold exceeds 12 dS/m.

- 3. Efficiency of Resistant Varieties (Table 3 Results):** The study revealed genetic variation offering a glimmer of hope for overcoming this crisis. Varieties such as "Salima" in Morocco, "Experimental 4" in Syria, and "Abu Ghraib 3" in Iraq demonstrated high to moderate salinity tolerance. The "Sham 6" variety, supported by the ACSAD Center, also emerged as a strategic option for areas with moderate salinity.

Concluding Recommendations

1. Utilize remote sensing technologies and drones for large-scale salinity monitoring.
2. Expand the cultivation of the varieties that have proven effective in Table (3), particularly in soils with salinity levels between 4 and 8 dS/m.
3. Integrate chemical solutions (such as agricultural gypsum) with biological solutions to improve the structure of sodium-affected soils.

In conclusion, soil salinity is not an isolated problem but is closely linked to water management and climate change. Therefore, addressing it requires a comprehensive approach that combines modern science with field experience to ensure sustainable food security.

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