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Mitigating The Effects of Salt Stress on The Growth and Yield of Soybean Cultivars (Glycine Max L.) By Kinetin Foliar Application

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Abstract

This research investigated the effect of salt stress from the use of relatively saline water on the growth and yield of soybean cultivars (*Glycine max* L.) through foliar application of the growth regulator kinetin. It was conducted at the Field Crop Research Station (FCRS), Field Crop Department, Tikrit University. The experiment employed two types of irrigation water namely river water from the Tigris River and well water of the research station. It also involved two treatments comprising kinetin and without kinetin growth regulator application, and four soybean cultivars, Shaima, Laura, Dee, and Lee. The experiment was applied using a Randomized Complete Block Design with as split-plot arrangement. Three plants were sourced during the soybean growing season from each experimental unit at 30, 60, 90, and 120 days after planting (DAP) to measure leaf area and dry weight to estimate relative growth rates (RGR), crop growth rates (CGR), and net assimilation rates (NAR). Chlorophyll content in the leaves was measured 50 DAP, and at the end of the season, oil percentages and yields were assessed. All studied traits were significantly affected by the quality of irrigation water, the application of the growth regulator kinetin, the soybean cultivars, and the interaction among these factors. For instance, irrigation with well water reduced chlorophyll content, oil percentage, and yield by 15%, 36%, and 17%, respectively compared to river water irrigation.

The findings show that the soybean crops in the Salah al-Din (Tikrit City) area which is characterized by gypsum soil, showed weak growth and yield. The use of river water irrigation, the Shaima cultivar, and kinetin did not elevate yield to global production standards.

Keywords: Soybean, Kinetin, Growth and development, Salinity, Irrigation.

التخفيف من آثار إجهاد الملح على نمو وإنتاجية أصناف فول الصويا (Glycine max L.) عن طريق الرش الورقي بالكاينتين

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الخلاصة

لدراسة تأثير الإجهاد الملحي الناتج عن استخدام مياه الابار على نمو وإنتاجية أصناف فول الصويا (Glycine max L.) من خلال رش الأوراق بمنظم النمو الكاينتين، تم إجراء التجربة الحقلية في محطة أبحاث قسم المحاصيل الحقلية في جامعة تكريت. تم استخدام نوعين من مياه الري في التجربة: مياه النهر (مياه نهر دجلة) ومياه الآبار (بئر في داخل محطة الأبحاث)، إلى جانب الرش الورقي بمنظم النمو كاينتين (الرش بالكاينتين وعدم الرش)، مع أربعة أصناف من فول الصويا (شيماء ولورا ودي ولي). تم تنفيذ التجربة باستخدام القطعات العشوائية الكاملة بنظام المنشقة مرتين. خلال موسم النمو للمحصول، تم أخذ ثلاث نباتات من كل وحدة تجريبية في 30 و60 و90 و120 يوما بعد الزراعة، لقياس مساحة الأوراق والوزن الجاف لتقدير معدل النمو النسبي ومعدل نمو المحاصيل ومعدل صافي التمثيل الضوئي. تم قياس محتوى الكلوروفيل في الأوراق بعد 50 يوم من الزراعة، وفي نهاية الموسم، تم حساب نسبة الزيت والحاصل. أشارت النتائج إلى أن جودة مياه الري، ورش منظم النمو الكاينتين، وأصناف فول الصويا، والتداخل بين هذه العوامل أثرت بشكل كبير على جميع الصفات المدروسة. أظهرت نتائج هذه الدراسة أن تحليل نمو محاصيل فول الصويا في بيئة مدينة تكريت، التي تتميز بتربة جبسة، أظهر ضعف النمو والمحصول. اذ لم يؤدي استخدام الري بمياه النهر، وصنف شيماء، ومنظم النمو الكاينتين إلى رفع المحصول إلى مستوى الإنتاج العالمي.

كلمات مفتاحية: فول الصويا، الكاينتين، النمو والتطور، الملوحة، الري.

Introduction

Soybean (*Glycine max* L.) is among the most important summer industrial legume crops, rich in amino acids, carbohydrates, fatty acids, and mineral nutrients (17). Its seeds contain a high oil content of 14 -24%, providing significant nutritional value due to the presence of most unsaturated fatty acids such as oleic, linoleic, and linolenic acids. Additionally, soybean seeds have a high protein content, ranging from 30 - 50% (35). Soybean is used to improve soil fertility through biological nitrogen fixation due to its symbiotic relationship with rhizobium bacteria.

The crop has other uses, including as forage, where the plant parts are consumed or its seeds processed into various feed forms, as a source for biofuel production and various medical uses (32). Three countries contribute 81% to global soybean production, namely Brazil (39%), the United States (29%), and Argentina (13%). Soybean cultivation and productivity in Iraq is low compared to neighboring countries such as Iran, Turkey, and Syria, with only 40 hectares planted (2021) and an average productivity of 0.78 tons per hectare.

Soil salinity or salt stress is one of the main environmental (abiotic) factors affecting plant growth, resulting in reduced and inhibited growth and productivity. The problem of salt stress mainly is exacerbated in arid and semi-arid regions due to high temperatures (26), such as the Iraqi environment. It is anticipated that the issue of soil salinity will intensify in the future and be a major factor lowering crop growth and yields due to climate change and the depletion of freshwater supplies appropriate for agricultural use (18). Approximately 25% of the world's arable land is affected by salt stress, losing an estimated 5.1 million hectares of productive land annually due to salinity (26). Salt stress generally reduces the ability of plants roots, including soybeans, which are sensitive to salinity, to absorb water and nutrients (12 and 13)

Growth regulators play a key role in increasing soybean seed yield due to their effective role in cell division and differentiation. They contribute to enhanced physiological efficiency, absorption, photosynthesis, respiration, and transpiration (8 and 17). One such regulator is kinetin, part of the cytokinin group, which some studies have shown to be important for increasing growth and production in soybeans (34), as well as mitigating damage from certain environmental stresses (28). Studying the effect of kinetin in alleviating damage caused by abiotic stresses in soybean plants is crucial for promoting the cultivation of this crop in regions with high temperatures, especially when irrigated with relatively saline water. The idea of using growth regulators to reduce abiotic stress is not new; however, it has not been extensively studied in soybeans in the Salah al-Din region. Consequently, this study investigated the impact of irrigation water quality, specifically well water and river water on the growth and yield of soybean cultivars. Additionally, it sought to assess the potential benefits of utilizing the growth regulator kinetin in enhancing these parameters.

Materials and Methods

A field experiment was conducted at the Agricultural Research Station of the Field Crops Department, Tikrit University, Tikrit, Iraq during the summer season of 2023 in gypsum soil (table 1). The three-factor factorial experiment was conducted using a split-split layout with three replications. The factors were type of irrigation water, growth regulator, and soy bean cultivars.

The experimental soil was plowed twice at right angles using a cultivator to break up the topsoil without turning it over, and the area was divided into three main plots. Each main plot consisted of four sub-plots assigned to the irrigation and growth regulator treatments, and each sub-plot was further divided into four sub-sub-plots for the soybean cultivars. The area of each experimental unit was 9 m² (3 × 3 m), resulting in a total of 48 experimental units. Before planting, the experimental area was fertilized with urea (nitrogen fertilizer) at a rate of 120 kg ha^{-1}, with half applied before planting and the other half added when the plants reached the fourth leaf stage (V4). Additionally, the experimental area was fertilized with triple superphosphate (46% P_2O_5) at a rate of 80 kg ha^{-1}, applied in one dose before planting.

Soybean seeds were planted using 3-4 seeds per hole at a depth of 3 cm. The plants were thinned to one plant per spot after reaching the third true leaf stage (V3). The planting was done in longitudinal rows with a distance of 0.75 m between rows and 0.10 m between holes, on the 5th of June 2023.

Irrigation was carried out using a drip irrigation method, with water lines isolated according to their source, river or well, each on its side. The experimental area was irrigated immediately after planting, and irrigation continued based on the plants' needs until the end of the season. The experimental area was manually weeded three times during the growing season.

At the end of the season, an analysis of soil electrical conductivity was conducted to assess the impact of the irrigation water by taking three random samples from different areas of the experiment (table 2).

Three factors were used in the experiment, including irrigation water, as the experiment was conducted according to the combinations of two types of irrigation water, the first sourced from the Tigris River and the other using well water. In order to control the quality of irrigation water, the two-way coefficients of each type were isolated in one direction to prevent mixing of the water. Spraying with the kinetin growth regulator was also done as the second factor in the experiment in addition to spraying with distilled water as a control treatment.

The kinetin was prepared by mixing 400 mg to 8 L^{-1} to form a mixture at a concentration of 50 ppm. The plants were sprayed twice, at the third true leaf (V3) and sixth true leaf (V6) stages before sunset using a 16-liter back spray until the leaves of the plant were completely wet. The four soybean cultivars i.e., Lee, Dee, Shaima, and Laura used in the experiment were sourced from the general company for industrial crops of the Iraqi Ministry of Agriculture.

Table 1: Physical and chemical qualities of the soil and irrigation water used in the experiment.

Soil traits	Value	Measurement units
pH	7.04*	
EC	2.61	Desi Sims meter^{-1}
CEC	10	Senti mol kg soil $^{-1}$
O.M	9.3	g Kg^{-1}
$CaCO_3$	120	g Kg^{-1}
$CaSO_4.2H_2O$	56.62	g Kg^{-1}
Positive and negative dissolved ions in the soil		
Ca^{++}	17.78	mm L^{-1}
Mg^{++}	13.12	
Na^{+}	6.95	
K^{+}	0.47	
Cl^{-1}	3.20	
HCO_3^{-1}	5.2	
CO_3^{-2}	0	
Soil texture	Sandy clay loam	
Clay	288	g Kg^{-1}
Loam	168	
Sand	544	
pH and electrical conductivity of the two types of irrigation water		
River water	pH	7.16
	EC	0.47
Well water	pH	6.55
	EC	2.78

*Soil and water analyses were conducted at the Department of Soil Science and Water resources at the Agriculture College, Tikrit University

Table 2: Electrical conductivity of the experiment soil at the end of the season.

Samples	Electrical conductivity
Soil irrigated with well water	4.01
Soil irrigated with river water	2.14

Among the indicators for analyzing growth in the soybean plant are relative growth rate (RGR), crop growth rate (CGR), and net assimilation rate (NAR) which contribute to the evaluation of crop performance under different growing conditions towards improving farming strategies. As such a growth analysis study was conducted to determine the nature of crop growth in gypsum soils under the conditions of the experiment. Three plants were selected every 30 days from the middle rows of each experimental unit and were measured for the following traits.

The leaf area of the plants was calculated by the dry weight method. A number of leaves were removed according to the size of the plant and 10 circular pieces cut out at the beginning of growth and 50 pieces at the end stages of the analysis using a cork cutter. The pieces were then dried and their areas determined using a mathematical equation. Also, all parts of the plant were air-dried and weighed to extract the dry weight (w) of the plant. Those measurements were then used to calculate the relative growth rate (RGR) which is a measure of the increase in the biological mass of a plant relative to the units of the total mass over a specified period of time. This is influenced by the type of dry matter produced by the plant during a specified period. The RGR indicates the efficiency of the plant in using the available water and nutrient resources to achieve growth and is based on the equation: RGR = (Ln w2-Lnw1)/(t2-t1).

Crop growth rate (CGR) measures the increase in plant biomass per unit of land area over a specified period of time. The CGR is of particular importance in assessing the productivity of a crop in agricultural fields and is based on the equation: CRG = 1/the area for plant × (w2-w1)/(t2-t1). The net assimilation rate (NAR) is a measure of the rate of photosynthesis of a plant per unit leaf area and expresses the efficiency of a plant in converting solar energy into chemical energy used for growth. It is measured by the following equation: NAR= (W2-W1)/(T2-T1) × (LN LA2-LN LA1)/(LA2-LA1. Chlorophyll content was estimated according to method mentioned by Richardson et al. (2002) where: Chla = 12.25 A663 - 2.79 A648; Chlb = 21.50 A648 – 5.10 A663; and Total Chl = Chla + Chlb.

The leaf area of three randomly selected plants was calculated from the median lines at 90 DAP and the rate extracted. The percentage of oil in seeds was measured using a Soxhlet extractor by taking 5g of random samples from the yield. Yield was calculated based on the quotient of an individual plant taken from 10 plants, multiplied by the plant density per unit area, and then converted to an area of hectares. Finally, the data was analyzed according to RCBD split-split plot design using SAS software (30) and the Duncan polynomial test was used to compare the averages of the coefficients at 0.05 probability level.

Results and Discussion

Relative Growth Rate: The analysis of variability showed that the different types of irrigation water had a significant impact on the relative growth rate (RGR) of the soybeans for the 3 plants life-cycle measurement periods of 30-60, 60-90, and 90-120 DAP. Irrigation with river water achieved significant superiority in the RGR by 18, 19, and 20% for the three measurement periods compared to well water (figure 1A). The salt in the well water (table 1) was probably the main factor raising the salinity of the soil and its pH, leading to lowered vital processes such as water and nutrient absorption, which ultimately affected RGR of the plants in the field. It is also noted that the rate of increase was increasing, which indicates that the process of accumulation of salts over time had a negative impact on the RGR. Similar results were reported by (11, 17 and 27).

Spraying kinetin had a significant impact on RGR with the plants significantly outperforming, by 19, 32, and 32%, for the three measurement periods compared to the plants not sprayed with the growth regulator (figure 1B). Apparently, spraying kinetin reduced the damage caused by the salt stresses from the well water irrigation, as well as improved the performance of plants irrigated with river water (table 1). This led to a positive cumulative effect of adding kinetin as it enhanced the relative growth rates of the plants as they aged. These results are consistent with (2 and 12).

The difference between the cultivars had a significant impact on the RGR of soybeans during the three DAP measurement stages. The Shaima cultivar strongly outperformed the other cultivars, that did not differ between them in RGR, giving a rate of 0.0172 and 0.0133 and 0.0155 g day^{-1} for the three measurement periods in a row (figure 1C). The Shaima had been cultivated in the study area (Tikrit city) not so long ago, and there is no doubt that its adaptation to the environmental conditions of the area greatly influenced its superior response compared to the others. This was also noted in many previous studies that focused on the impact of the cultivars on the growth and development of the soybean (32).

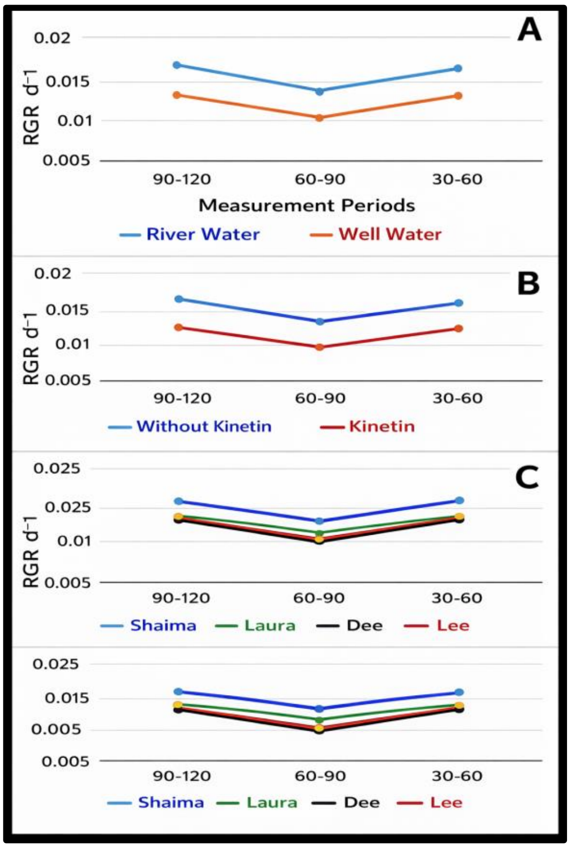

Figure 1: The effect of water type (A), kinetin spraying (B), and cultivar (C) on the RGR of the soybean plants for the different growth stages.

The two-factor interaction of kinetin×cultivars had a significant effect on the soybean RGR and for the three measurement stages (Supplements 1, 2, and 3). The kinetin×Shaima interaction significantly exceeded the others of the same category and during the measurement stages to give a RGR of 0.0204 g day^{-1} for the 30-60 DAP, 0.0175 g day^{-1} (60-90 DAP), and 0.0181 g day^{-1} (90-120 DAP). The without-kinetin×Laura interaction gave the lowest RGR for the 30-60 DAP factor at 0.0123 g day^{-1} while that without kinetin×(Shaima, Laura, Lee, and Dee) had the lowest RGR for the 60-90 DAP ranging from 0.0087 - 0.0103 g day^{-1}.

This did not differ significantly among them, but in the 90-120 DAP measurement phase the without kinetin×(Laura, Lee, and Dee) gave the lowest RGR ranging from 0.0110 - 0.0116 g day^{-1} compared to two factors interaction of the same category. The two interaction factor results might have been significant due to the cumulative effects of the two cultivars and the superiority of the cultivar in RGR, which influenced the outcome to show this overlap distinct from the other interventions of the same category.

Moreover, it was found that the kinetin×irrigation water two-factor interaction significantly influenced the RGR of the soybean plants (Supplements 1, 2, and 3). The kinetin×river water interaction significantly exceeded, giving the highest RGR at 0.0180, 0.0153, and 0.0191 g per day^{-1} for the 30-60, 60-90, and 90-120 DAP respectively, compared to the two factors interaction of the same category. Meanwhile, the two factors interaction without kinetin×well water for the 30-60 DAP and without kinetin×river water in the 60-90 and 90-120 DAP gave the lowest RGR values.

The effect of river water irrigation and kinetin spraying showed significant distinction as single factors; so, it is normal that their interaction excels compared to other two factor interactions. What is striking in these two factors interaction, however, was that kinetin×well water had significantly superior values over without kinetin×well water for all the DAP periods, thus showing the importance of kinetin in mitigating the damage caused by irrigation with well water. On the other hand, the cultivar×irrigation water interaction significantly affected the soybean RGR. The Shaima×river water was significantly superior giving the highest RGR for the 30-60 DAP period at 0.0190 g day^{-1}, while the well water×(Laura, Lee, and Dee) two-way interaction gave the lowest RGR, and not significantly different among each other in the same measurement period.

Also, the 60-90 and 90-120 DAP measurement periods for the Laura×river water interaction was superior by giving the highest RGR. This overlap did not differ materially from the Laura, Lee, and Dee×river water, and Shima×well water in the 60-90 DAP period and did not differ materially from the interaction of Laura×river water in 90-120 DAP period. Meanwhile, the Laura×well water, Lee×well water and Lee×well water interactions gave the lowest RGR for the 30-60, 60-90 and 90-120 DAP, respectively. The RGR superiority of the Shaima cultivar over the others, as well as the superiority of river- over well-water irrigation, led as a result to the enhanced two factor interaction of Shaima×river water over the other similar interactions in the same category.

The triple interventions of kinetin×cultivars×irrigation water showed a significant effect on the RGR of the soybean (Supplements 1, 2, and 3). The triple interference of kinetin×Shaima×river water had the highest RGR, reaching 0.020, 0.0181, and 0.0203 g day^{-1} for the 30-60, 60-90, and 90-120 DAP periods, respectively. Meanwhile, the without-kinetin×Laura×well water, without kinetin×Dee×well water, and without kinetin×Laura×well water gave the lowest RGR at 0.010, 0.0072, and 0.0099 g day^{-1} for the 30-60, 60-90, and 90-120 DAP, respectively. It is clear that the influence of individual factors on the triple interference was positive as the addition of kinetin, the distinction of the Shaima cultivar, and irrigation with river water led to the superiority of the kinetin×Shaima×river water interaction over the other triple interferences.

Crop Growth Rate: The crop growth rate (CGR) is one of the basic indicators for assessing the performance of plants and their efficiency in using available environmental resources to achieve growth and production within a given environment. Variation analysis showed that irrigation water type significantly affected the CGR of the soybeans plants with those provided river water exceeding the well-water ones by 11, 14, and 13% for the 30-60, 60-90, and 90-120 DAP periods, respectively (figure 2A).

Among the environmental factors affecting the CGR, salinity is one of the most important challenges facing the cultivation of field crops, including soybeans. The high soil salinity (table 2) from irrigating with well water affected the performance of the crop and its composition of dry matter, thus contributing to lower CGR. Also, the percentage difference between river and well water irrigation increased by 3% between the 30-60 and 60-90 DAP periods, thus confirming that adding water containing salts (table 1) and the accumulation of salts in the soil (table 2) led to a lower CGR. These results are consistent with those reported by (25).

According to the variance analysis, spraying the soybean plants with kinetin significantly impacted the CGR, exceeding 20, 37, and 22% for the 30-60, 60-90, and 90-120 DAP measurement periods, respectively compared to the plants not receiving the kinetin (figure 2B). It is clear that the growth regulator kinetin improved the performance of the soybean plants at the physiological level, increasing their dry matter production per unit area over those not treated with kinetin. Similar results were noted by (4 and 7).

The influence of cultivars varied in the CGR at different growth stages. The Shaima was significantly superior in the 30-60 and 90-120 DAP growth stages, though not significantly different from the Laura at the 30-60 DAP period, while the cultivars did not vary significantly among themselves in the 60-90 DAP growth stage (figure 2C). Cultivars differ in growth rates depending on their genetic nature and adaptation to their environments (39), as reflected in the amount of dry matter they produce per unit area. Similar results for varietal heterosis were reported by (34).

The two-factor interaction of kinetin×cultivars showed a significant effect on soybean CGR and for the three measurement stages (Supplements 4, 5, and 6). The kinetin×Shaima significantly exceeded the others in the same category during the three measurement stages giving CGRs of 0.000178 g cm^{-2} day^{-1} for the 30-60 DAP, 0.000205 g cm^{-2} day^{-1} for the 60-90 DAP, and 0.000305 g cm^{-2} day^{-1} for the 90-120 DAP. The two-factor interaction without kinetin×(Shaima, Laura, Dee, and Lee) had the lowest CGR for the 30-60 DAP period in the range of 0.000125-0.000128 g cm^{-2} day^{-1}, respectively. Meanwhile, the without kinetin×(Shaima, Laura, Lee, and Dee) interaction had the lowest CGR for 60-90 DAP period (0.000117- 0.000125 g cm^{-2} day^{-1}) and did not differ significantly among themselves at the 90-120 DAP period (Supplements 4, 5, and 6).

The two factors interaction without kinetin×(Shaima, Laura, Lee, and Dee) gave the lowest CGR (ranging from 0.000212 to 0.000225 g cm^{-2} day^{-1}) compared to that of the same category. The interaction of kinetin and cultivars results shown may be due to the effects of spraying with a growth regulator and the CGR superiority of the cultivar, which influenced the outcome to show this interference as distinct from other interventions of the same category.

Similarly, the two-factor interaction of kinetin×irrigation water had a significant impact on the CGR of the soybean crop (Supplements 4, 5, and 6). The kinetin×river water interaction exceeded by giving the highest CGR of 0.000165, 0.000206, and 0.000300 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP measurement periods, respectively compared to the two factors interaction of the same category. Meanwhile, the without-kinetin×well water interaction in all measurement periods gave the lowest CGR, lagging behind the others in the interaction for the same category. The effect of irrigation with river water and spraying with the two reagents showed a distinction as single factors, giving their interaction a significant superiority over the other two factors interaction of the same category.

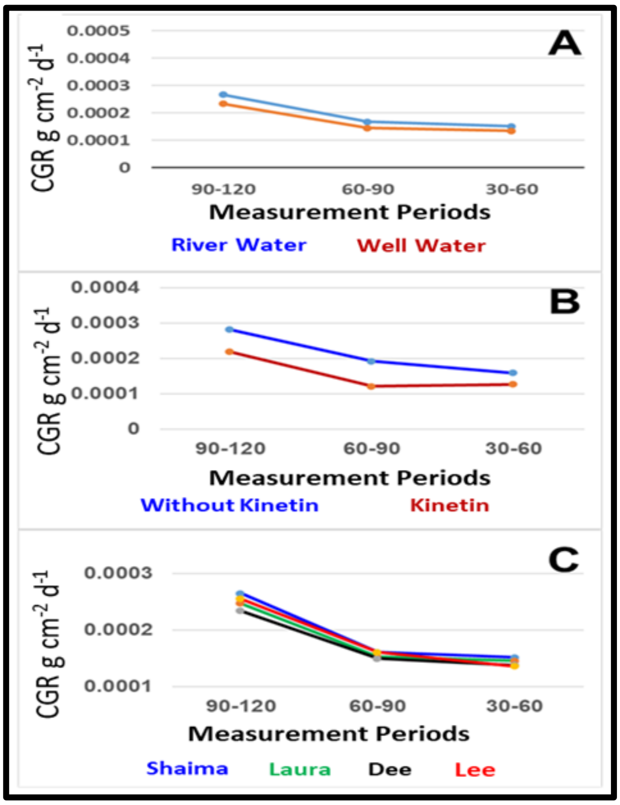

Figure 2: The effect of water type (A), kinetin spraying (B), and cultivars (C) on the CGR of the soybean plants for the different growth stages.

Supplements 4, 5, and 6 showed that the effect of the two factors interaction cultivars×irrigation water significantly affected the soybean CGR. The Shaima×river water interaction had the highest CGR, reaching 0.000165, 0.000168, and 0.000285 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP periods, respectively, and did not differ significantly from the Laura, Lee, and Dee river water treatment for the 60-90 DAP period. The Shaima cultivar's superiority over the others as well as the superiority of river over well water irrigation led to its advantage over the interactions in the same category.

The triple intervention of kinetin×cultivars×irrigation water had a significant effect in CGR of the soybean crop. The kinetin×Shaima×river water recorded the highest CGRs of 0.000180, 0.000213 and 0.000327 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP measurement periods, respectively. This did not differ significantly from the kinetin×Laura×river water (0.000163 g cm^{-2} day^{-1}) and kinetin×Shaima×well water (0.000177 g cm^{-2} day^{-1}) for the 30-60 DAP period (Supplements 4, 5, and 6). It also did not differ significantly from the kinetin×Laura×river water (0.000212 g cm^{-2} day^{-1}), kinetin×Lee×river water (0.000200 g cm^{-2} $days^{-1}$), kinetin×Dee×river water (0.000193 g cm^{-2} $days^{-1}$), and the kinetin×Shaima×well water (0.000197 g cm^{-2} $days^{-1}$) for the 60-90 DAP period. Meanwhile, the triple interventions of without-kinetin×Shaima×well water for the 30-60 and 60-90 DAP and kinetin×Dee×well water 90-120 DAP periods gave the lowest CGR. The individual factors positively influenced the triple interference, as the kinetin, Shaima cultivar, and river water irrigation led to the superiority of their triple interference over the other similar interventions in CGR.

Net Assimilation Rate: Net assimilation rate (NAR) is one of the most important indicators of the efficiency of the basic vital processes that plants rely on to achieve growth and development. It is defined as the difference between the amount of solar energy (sunlight) absorbed by plants during carbon metabolism and the amount of energy used in respiration processes. The results show that type of irrigation water had a significant impact on NAR, with soybean plants irrigated with river water significantly outperforming their well-water counterparts by 4, 16, and 11% for the 30-60, 60-90, and 90-120 DAP periods, respectively (figure 3A). The higher difference ratios between the 30-60 and 60-90 DAP periods indicate increased salt concentrations in the soil from irrigating with well water, which negatively affected the plats' NARs.

Higher soil salinity reduces the ability of roots to absorb water, causing dehydration in plant tissues, that negatively affects the processes of carbon metabolism, as plants need water to achieve water balance and facilitate the transfer of nutrients. Alternatively, the higher soil salinity could have led to a shortage of essential nutrients such as potassium and calcium (due to competition with sodium) thereby hindering plant growth, and decreased the efficiency of carbon metabolism and net photosynthesis. Similar results were reported by (28).

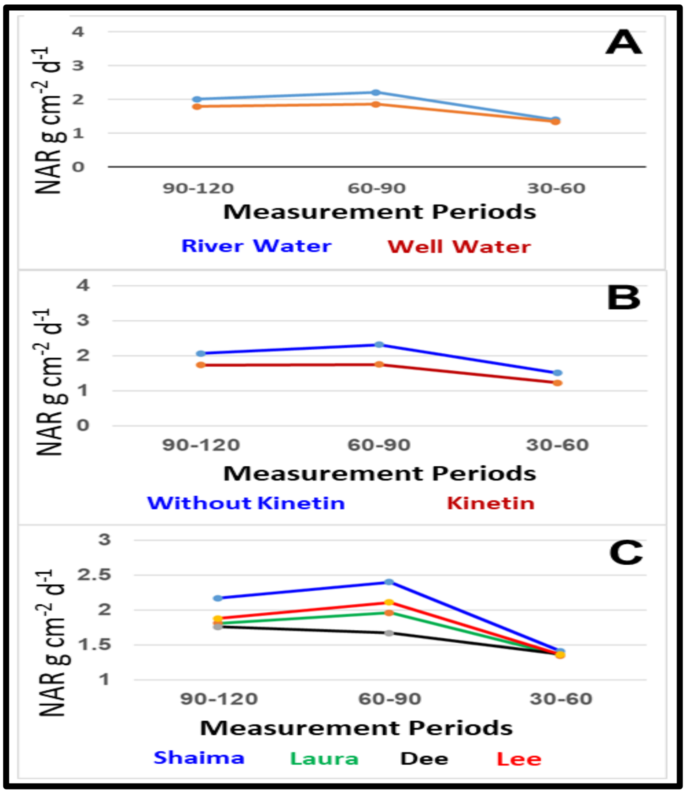

Figure 3: The effect of water type (A), kinetin spraying (B), and cultivar (C) on the NAR of soybean plants for the different growth stages.

Spraying with the growth regulator kinetin significantly affected the NAR of soybean plants compared to those not sprayed, giving an increase in the rate of 16, 25 and 16% for the 30-60, 60-90, 90-120 DAP measurement periods, respectively (figure 3B). This may be due to the positive effect of kinetin on several aspects of growth and development in soybeans, as it stimulates vegetative growth such as leaves and stems. This leads to larger leaf areas, that positively impact the plant's ability to carry out the process of carbon metabolism (29). It could also be due to the ability of kinetin to improve soybean tolerance to environmental stresses such as salinity, as it enhances metabolic processes and increases water-use efficiency (1, 2, 14 and 18).

The analysis showed that the soybean cultivars in the experiment did not differ significantly in the first measurement period (30-60 DAP), though the Shaima was significantly superior, having highest NAR rates of 2.40 and 2.17 g cm^{-2} day^{-1} for the 60-90 and 90-120 DAP periods (figure 3C). The heterogeneity of soybean cultivars is one of the main factors affecting net photosynthesis, as they differ among themselves through variants in physiological and genetic characteristics, which consequently affects the efficiency of carbon metabolism and NAR (24). Cultivars differ in their ability to absorb sunlight for the process of carbon metabolism, with some having higher levels of chlorophyll pigment, which increases their ability to convert solar energy into chemical energy (3 and 16). Soybean cultivars also respond differently to environmental conditions and stresses; for example, some are more tolerant than others, and these usually show higher efficiency in photosynthetic reactions.

The two-factor kinetin×cultivar interactions showed a significant effect on soybean NAR for the three measurement stages (Supplements 7, 8, and 9). The kinetin×Shaima interaction had the highest NARs of 1.62, 2.88, and 2.37 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP measurement periods, respectively, compared with interactions in the same category with the exception of 2.50 g cm^{-2} day^{-1} for the 60-90 DAP which did not differ significantly from the kinetin×Shaima interaction. Meanwhile, the without-kinetin×(Shaima, Laura, Lee, and Dee) for the 30-60 and 60-90 DAP periods and the interaction without kinetin×(Laura, Lee, and Dee) in the 90-120 DAP showed the lowest NAR. The high level of significance of the individual factors (kinetin and cultivars) resulted in the such a pronounced heterogeneity between the interferences in the NAR.

Moreover, it was found that the kinetin×irrigation water interaction had a significant impact on the NAR of the soybean plants. The kinetin×river water interaction had the highest NARs at 1.58, 2.57, and 2.21 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP periods, respectively (Supplements 7, 8, and 9). However, the two-factor interactions and the 30-60 and 60-90 DAP periods had the lowest rate of net photosynthesis and did not differ significantly from each other, while the without-kinetin×well water for the 90-120 DAP measurement registered the lowest NAR in comparison with the two-factor interaction of the same class. The high quality of the single factors (kinetin and irrigation water) resulted in this clear heterogeneity between the interferences in NAR.

Supplements 7, 8, and 9 showed that the effect of the two factors interaction of cultivars×irrigation water significantly affected the NAR of the soybean crop. The Shaima×river water interaction had the highest NAR in all measurement periods, reaching 1.48, 2.55, and 2.19 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP periods, respectively. It did not differ significantly from the Laura and Lee×river water, and Laura×well water for the 30-60 DAP, as well as the Lee×river and Shima×well waters for the 60-90 and 90-120 DAP periods. The high quality of individual factors (cultivars and irrigation water) may be the main factor that led to the existence of such a clear discrepancy between the overlaps in the NAR.

The triple interventions of kinetin×cultivars×irrigation water showed a significant effect on the NAR of the soybean plants (Supplements 7, 8, and 9). The kinetin×Shima×river water significantly exceeded the others with NARs of 1.69, 3.20, and 2.38 g cm^{-2} day^{-1} for the 30-60, 60-90, and 90-120 DAP measurement periods, respectively. They did not differ significantly from the kinetin×Lee×river water in the 30-60 and 90-90 DAP and the kinetin×(Laura, Dee, and Lee)×river water for the 90-120 DAP. The without-kinetin×Shaima×well water decreased significantly from the other triple interferences in 30-60 DAP period at 1.13 g cm^{-2} day^{-1}.

Moreover, the triple interference gave the lowest NAR (1.26 g cm^{-2} day^{-1}) for the 60-90 DAP and did not differ significantly from that without-kinetin× Laura ×well water, without-kinetin×Dee×well water, and without-kinetin×Lee×well water. Also, the triple interference without-kinetin×Laura×well water gave the lowest NAR (1.49 g cm^{-2} $days^{-1}$) for the 90-120 DAP period, not significantly different from the without-kinetin×Laura and Dee×river water and without-kinetin×Dee×well water and without kinetin×Lee. The singularity of the factors (kinetin, river water, and Shaima cultivar) resulted in these changes in the three interferences.

Chlorophyll Content of the Soybean: Chlorophyll is one of the important and essential pigment for carbon metabolism, as it enables plants, including soybean plants, to convert solar energy (sunlight) into chemical energy, which is reflected on plant growth and productivity. Plants irrigated with river water were 15% more superior in containing higher amounts of chlorophyll compared to those irrigated with well water (table 3). The choice of irrigation water is a decisive factor in promoting plant health and productivity. The quality of irrigation water significantly affects the chlorophyll content of leaves as it has relatively high levels of salt (table 1). This causes plant environmental stress, which reduced its synthesis of chlorophyll and negatively affected the process of carbon metabolism (10, 16, and 22).

Spraying with the growth regulator, kinetin, had a significant effect on the chlorophyll content of leaves amounting to 11% compared to plants that were not sprayed (table 3). Such spraying of soybean plants has a catalytic and vital role in enhancing the chlorophyll content in soybean leaves, as kinetin contributes to improving the efficiency of carbon metabolism. Studies indicate that kinetin applications increase chlorophyll concentrations in soybean leaves, which enhances the plant's ability to absorb light (29).

The Shaima cultivar had the highest leaf chlorophyll content by 11, 16, and 7% over the Laura, Dee and Lee cultivars, respectively, while the Dee had the lowest (27.44 mg g^{-1}), not significantly different from the Laura cultivar (29.00 mg g^{-1}) (table 3). Studies show some cultivars having the ability to produce larger amounts of chlorophyll than others, which enhances their ability to absorb light and improved the efficiency of carbon metabolism (23 and 34).

Table 3 showed that the two-factor interaction of kinetin×cultivars was significant in leaf chlorophyll content with the kinetin×Shaima interference registering the highest chlorophyll content of 35.63 mg g^{-1}. The without-kinetin×Dee (25.08 mg g^{-1}) and without-kinetin×Lee (28.46 mg g^{-1}) were the least significant in the same category. The fact that the Shaima cultivar is distinguished from the other cultivars with its ability to benefit from kinetin may have contributed to the bilateral overlap of kinetin×Shaima at the highest quality level.

Moreover, the kinetin×irrigation water interaction had a significant impact on the rate of chlorophyll content of leaves. The kinetin×river water interaction significantly exceeded the others by giving the highest leaf chlorophyll content (34.03 g mg^{-1}), while the without-kinetin×well water was significantly lower in the same category interaction (25.84 g mg^{-1}). It is clear that the type of irrigation water used and the addition of the growth regulator kinetin produced the abovementioned results.

The effect of two factors interaction of cultivars×irrigation water significantly affected leaf chlorophyll content (table 3). The Shaima×river water interaction significantly exceeded the others in the same category with leaf chlorophyll content amounting to 34.07 g mg^{-1}. This was not significantly different from the Laura×river water (32.00 g mg^{-1}), Lee×river water (32.56 g mg^{-1}), and Shaima×water well (31.28 g mg^{-1}) interactions. Meanwhile, the Laura×well water (26.00 g mg^{-1}) and Dee×well water (24.93 g mg^{-1}) interactions were the least significant in the same category. It seems that the influence of single significant factors (cultivars and irrigation water) contributed to the synthesis of the importance of the two factors' interaction effect.

The triple intervention of kinetin×cultivars×irrigation water showed a significant effect on leaf chlorophyll content of the soybean crop plants. The kinetin×Shaima×river water markedly exceeded the others at a chlorophyll content of 38.39 g mg^{-1}, while the without-kinetin×Dee×well water (23.29 g mg^{-1}) decreased significantly from the others except for the without-kinetin×Dee×river water, without-kinetin×Laura×well water, without-kinetin×Lee×well water, kinetin× Laura×well water and kinetin×Dee×well water. The influence of individual factors (kinetin spraying, cultivars, irrigation water type) contributed to raising the relative growth rate (RGR), crop growth rate (CGR), and the net photosynthesis rate (NAR), which led to the above results.

Table 3: Impact of irrigation water and kinetin foliar spray on the leaf chlorophyll content (mg g^{-1}) of the soybean cultivars.

Water type	**Kinetin**	**Cultivars**				**Kinetin×water**	**Water type**
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	29.76 bcd	32.57 b	26.87 cde	31.87 b	30.27 b	32.15 a
	Kinetin	38.39 a	31.43 bc	33.04 b	33.25 b	34.03 a	
Well	Without Kinetin	29.69 bcd	25.33 de	23.29 e	25.05 de	25.84 c	27.47 b
	Kinetin	32.87 b	26.66 cde	26.56 cde	30.31 bc	29.10 b	
Without kinetin×cultivar		29.73 b	28.95 b	25.08 c	28.46 bc	Kinetin	
Kinetin×cultivar		35.63 a	29.05 b	29.80 b	31.78 b	Without kinetin	Kinetin
Cultivar×river water		34.07 a	32.00 ab	29.95 bc	32.56 ab	28.05 b	31.56 a
Cultivar×well water		31.28 ab	26.00 d	24.93 d	27.68 cd		
Cultivar		32.68 a	29.00 bc	27.44 c	30.12 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Soybean Oil Percentage: The percentage of oil in soybeans is one of the basic characteristics for determining its nutritional and market value. Table 4 showed that the quality of water type had a significant impact on the oil content in soybean seeds.

Plants irrigated with river water (28%) outperformed those receiving well water (18%) with their seeds containing a higher percentage of oil with a significant difference of up to 36%. The types of irrigation water shown in tables 1 and 2 showed variable salinity content which is expected to affect the salinity of the soil. This negatively impacted the absorption of nutrients such as nitrogen, phosphorus, and potassium, thereby reducing the content of chlorophyll in the leaves (table 3), and likely affecting the production and storage of oil in the seeds.

Table 4 showed that kinetin spraying had a significant positive effect on seed oil content of 26%, while plants not treated with kinetin had a lower rate of 20%. The addition of a growth regulator by spraying contributed to an increase in secondary reactions leading to a higher percentage of oil compared to the untreated plants. Similar results were obtained by (15).

The cultivars showed significant heterogeneity, with the Shaima cultivar being superior in producing the highest oil content of 27% compared to the others. The Dee cultivar had the lowest figure at 20%, not significantly different from Laura's 22% seed oil content (table 4). Soybean cultivars differ in their seed oil content (29) due to their varied ability to produce different amounts of chlorophyll (table 3), and leaf sizes (6 and 8), which affects their capacity to absorb light and carbon metabolism (25) and eventually the oil content of their seeds (2).

Table 4 showed the significant effect of the two-factor kinetin×cultivar interaction on oil content. The kinetin×Shaima interaction produced the highest oil content of 30%, while that without-kinetin×Dee at 18% was the least significant and fairly similar to the without-kinetin×Laura (19%) and ×Lee (21%) interactions. The quality of the Shaima cultivar and its adaptation to the environment compared to the others coupled with its ability to benefit from kinetin may have contributed to an increase in nutrient absorption, especially nitrogen. This allowed for the double overlap of kinetin×Shaima having the highest significant oil content trait in the seeds.

On the other hand, the kinetin×irrigation water interaction significantly influenced seed oil content. The kinetin×river water interaction produced the highest amount of oil content in seeds (31%), while that without-kinetin×well water was much lower at 15%, a 52% decline. This showed the extent of interaction of the growth regulator kinetin with plants irrigated with river water, which reflected positively on the content of oil in the seeds.

Table 4 showed the positive effect of the cultivars×irrigation water interaction on the amount of seed oil. The Shaima×river water interaction produced significantly higher oil content than the others at 32%, compared to the lowest at 16% for the Dee×well water interaction, and did not differ much from the 18% for the Laura and Lee well water interactions. The influence of single significant factors (cultivars and irrigation water) apparently contributed significantly towards the two-factor interactions in percentage of oil in the seeds.

The triple kinetin×cultivars×irrigation water interaction had a significant effect on the ratio of oil in the seeds of the soybean crop. At 35%, the kinetin×Shaima×river water interaction heavily exceeded the other triple interferences, compared to the 14% for the without-kinetin×Dee×well water interaction which did not differ from the 15% for both the without-kinetin×Laura and Lee×well water as well as the 18% for the kinetin×Dee×well water. The influence of individual factors (spraying with kinetin, cultivars, and irrigation water quality) contributed to raising the RGR, CGR, and NAR, as well as contributed to the higher leaf chlorophyll content (table 3), leading to the above results.

Table 4: Impact of irrigation water and kinetin foliar spray on the oil content of the soybean cultivar seeds (%).

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	0.29 bc	0.24 def	0.23 def	0.26 cd	0.25 b	0.28 a
	Kinetin	0.35 a	0.29 bc	0.27 cd	0.31 ab	0.31 a	
Well	Without Kinetin	0.18 gh	0.15 h	0.14 h	0.15 h	0.15 d	0.18 b
	Kinetin	0.25 cde	0.20 fg	0.18 gh	0.22 efg	0.21 c	
Without kinetin×cultivar		0.23 cd	0.19 e	0.18 e	0.21 ed	Kinetin	
Kinetin×cultivar		0.30 a	0.25 bc	0.22 cd	0.27 b	Without kinetin	Kinetin
Cultivar×river water		0.32 a	0.27 bc	0.25 c	0.29 b	0.20 b	0.26 a
Cultivar×well water		0.22 d	0.18 e	0.16 e	0.18 e		
Cultivar		0.27 a	0.22 bc	0.20 c	0.24 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Soybean Yield: The yield of soybean plants is influenced by biotic and abiotic factors related to the quality of their genetic structures and environmental conditions. Table 5 showed that irrigation water significantly affected soybean plant yields. River water irrigation produced a soybean plant yield of 2.04 ton ha^{-1}, significantly superior by 17% to those receiving well water at 1.69 ton ha^{-1}. The quality of irrigation water affected the RGR (figure 1), CGR (figure 2), and NAR (figure 3). It also had an impact on the chlorophyll content of the leaves (table 3), which reflected on the yield. Similar results were reported by (5, 18, and 29).

Spraying soybean plants with the kinetin growth regulator had a significant impact on yield at 2.06 ton ha^{-1}, much superior to the non-sprayed plants that produced 1.67 ton ha^{-1}, an increase of 19% (table 5). The effect of kinetin was apparent on the growth qualities (leaf chlorophyll content), which ultimately led to increased yields. Similar results were reported by (12, 20, 26 and 27).

Table 5 also showed that Shaima cultivar was superior giving the highest yield of 2.34 ton ha^{-1}, while the others had lower results and did not differ much among themselves. The Laura, Dee, and Lee cultivars, for instance, yielded 1.70, 1.65, and 1.77 ton ha^{-1}, respectively. Cultivars differ in terms of their chlorophyll content (13 and 21), propensity for carbon metabolism (38) and, consequently, on the production of horns (17), leading to differences in the yield (9 and 33).

The two-factor interaction of kinetin×cultivars significantly affected the yield of soybean plants (table 5). The kinetin×Shaima interaction produced the highest seed yield of 2.60 ton ha^{-1}, while the without-kinetin×Lee interaction result at 1.40 tons ha^{-1}) was the lowest. It did not differ from the without kinetin×Laura and Dee at 1.49 and 1.72 ton ha^{-1}, respectively and kinetin×Dee (1.59 ton ha^{-1}). The quality of the Shaima cultivar and its adaptation to the environment together with its ability to benefit from kinetin may have contributed to the kinetin×Shaima interaction having the highest characteristic in the final product.

Furthermore, the two factors interaction of kinetin×irrigation water had a significant impact on final plant yield. The kinetin×river water interaction was significantly higher than the other interventions for the same category by giving the highest yield (2.27 ton ha^{-1}). Meanwhile, the two factors interaction without kinetin×well water decreased significantly from other bilateral interventions in the same category (1.52 ton ha^{-1}). Thus, it is apparent that irrigation water type (river) has a major role together with the growth regulator in increasing carbon representation, which made a difference in the final yield result.

Table 5 showed that the two-factor cultivars×irrigation water interaction had a significant impact on soybean plant yield. The Shaima×river water significantly exceeded the others in the content of seed yield at 2.43 ton ha^{-1}. This did not differ significantly from the Shaima×well water yield of 2.24 ton ha^{-1}, while the Laura×well water at 1.38 ton ha^{-1} was the least significant and did not differ much from the Dee×well water (1.39 ton ha^{-1}) and Lee×well water (1.75 ton ha^{-1}). The influence of single significant factors (cultivars and irrigation water) contributed to the the significance of these bilateral overlaps.

Table 5 also showed the significant effect of the triple interactions of Kinetin×cultivars×irrigation water on soybean yield. The kinetin×Shaima×river water exceeded the others at 2.64 ton ha^{-1}, not much different from the without-kinetin×Shaima×river water (2.22 ton ha^{-1}), kinetin×Shaima×well water (2.57 ton ha^{-1}) and kinetin×Lee×well water (2.18 ton ha-1). Meanwhile, the triple interference kinetin×Dee×well water recorded a lower yield (1.09 ton ha^{-1}), and it was not significantly different from the without-kinetin×Lee×river water (1.48 ton ha^{-1}) and without kinetin×Laura×well water (1.17 ton ha^{-1}) and without kinetin×Lee×well water (1.32 tons ha^{-1}) and kinetin×Laura×well water (1.58 ton ha^{-1}). The influence of individual factors (kinetin spraying, cultivars, and irrigation water type) contributed to raising the RGR, CGR, and NAR (figures 1, 2, and 3), as well as contributed to increasing leaf chlorophyll content (table 3), which led to the above results.

Table 5: Impact of irrigation water and kinetin foliar spray on soybean cultivar yield (ton ha^{-1}).

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	2.22 a-d	1.82 c-g	1.75 c-g	1.48 f-i	1.82 b	2.04 a
	Kinetin	2.64 a	2.25 abc	2.09 b-e	2.10 b-e	2.27 a	
Well	Without Kinetin	1.92 c-f	1.17 hi	1.69 d-h	1.32 ghi	1.52 c	1.69 b
	Kinetin	2.57 ab	1.58 e-i	1.09 i	2.18 a-d	1.86 b	
Without kinetin×cultivar		2.07 bc	1.49 e	1.72 cde	1.40 e	Kinetin	
Kinetin×cultivar		2.60 a	1.92 bcd	1.59 de	2.14 b	Without kinetin	Kinetin
Cultivar×river water		2.43 a	2.03 bc	1.92 bc	1.79 c	1.67 b	2.06 a
Cultivar×well water		2.24 ab	1.38 d	1.39 d	1.75 cd		
Cultivar		2.34 a	1.70 b	1.65 b	1.77 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Conclusions

This study compared the effects of irrigation water type and the kinetin growth regulator on some soybean cultivars in enhancing their resistance to salinity and in growth capability. It found that kinetin application improved growth indicators, such as RGR, CGR, NAR, leaf chlorophyll content, oil percentage, and yield, even under saline conditions. Additionally, kinetin assisted in mitigating salinity stress by enhancing the metabolic activities of plants. These outcomes indicate that kinetin is an effective tool for refining soybean adaptability to salinity, thereby enhancing productivity in salinity-affected areas. It also underscores the need for mixing water management strategies with growth regulators to boost agricultural production in challenging environments.

Supplementary Materials:

Supplement 1: Impact of irrigation water, and kinetin foliar spray on the RGR of soybean cultivars (gm day^{-1}) at 30-60 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	0.015 cd	0.014 cde	0.013 de	0.013 de	0.014 b	0.016 a
	Kinetin	0.023 a	0.018 b	0.017 bc	0.015 bcd	0.018 a	
Well	Without Kinetin	0.014 cde	0.010 f	0.012 ef	0.013 de	0.012 c	0.013 b
	Kinetin	0.016 bc	0.13 de	0.013 de	0.013 de	0.014 b	
Without kinetin×cultivar		0.015 bc	0.012 e	0.013 de	0.013 cde	Kinetin	
Kinetin×cultivar		0.020 a	0.016 b	0.015 bc	0.014 bcd	Without kinetin	Kinetin
Cultivar×river water		0.019 a	0.16 b	0.015 bc	0.014 bcd	0.013 b	0.016 a
Cultivar×well water		0.015 b	0.012 e	0.013 de	0.013 cde		
Cultivar		0.017 a	0.014 b	0.014 b	0.014 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 2: Impact of irrigation water and kinetin foliar spray on the RGR of soybean cultivars (gm day^{-1}) at 60-90 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	0.0097 efg	0.0106 d-g	0.0116 c-f	0.0098 efg	0.0104 c	0.0129 a
	Kinetin	0.0181 a	0.0152 abc	0.0139 bcd	0.0140 bcd	0.0153 a	
Well	Without Kinetin	0.0084 fg	0.0100 efg	0.0072 g	0.0075 g	0.0083 d	0.0104 b
	Kinetin	0.0168 ab	0.0095 efg	0.0105 d-g	0.0130 cde	0.0124 b	
Without kinetin×cultivar		0.0091 d	0.0103 cd	0.0094 d	0.0087 d	Kinetin	
Kinetin×cultivar		0.0175 a	0.0124 bc	0.0122 bc	0.0135 b	Without kinetin	Kinetin
Cultivar×river water		0.0139 a	0.0129 a	0.0127 ab	0.0119 abc	0.0094 b	0.0139 a
Cultivar×well water		0.0126 ab	0.0098 cd	0.00889 d	0.0102 bcd		
Cultivar		0.0133 a	0.0114 b	0.0108 b	0.0110 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 3: Impact of irrigation water and kinetin foliar spray on the RGR of soybean cultivars (gm day^{-1}) at 90-120 DAP.

Water type	**Kinetin**	**Cultivars**				**Kinetin×water**	**Water type**
		Shaima	Laura	Dee	Lee		
River	With out Kinetin	0.0144 cd	0.0121 efg	0.0124 def	0.0127 de	0.0129 c	0.0160 a
	Kinetin	0.0203 a	0.0120 a	0.0184 ab	0.0179 b	0.0191 a	
Well	With out Kinetin	0.0115 e-h	0.0099 h	0.0102 gh	0.0104 fgh	0.0105 d	0.0128 b
	Kinetin	0.0158 c	0.0154 c	0.0142 cd	0.0152 c	0.0151 b	
Without kinetin×cultivar		0.0130 c	0.0110 d	0.0113 d	0.0116 cd	Kinetin	
Kinetin×cultivar		0.0181 a	0.0177 ab	0.0163 b	0.0165 b	With out Kinetin	Kinetin
Cultivar×river water		0.0173 a	0.0160 ab	0.0154 b	0.0153 b	0.0117 b	0.0171 a
Cultivar×well water		0.0137 c	0.0127 cd	0.0122 d	0.0128 cd		
Cultivar		0.0155 a	0.0143 b	0.0138 b	0.0140 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 4: Impact of irrigation water and kinetin foliar spray on the CGR of soybean cultivars (gm cm^{-2} day^{-1}) at 30-60 DAP.

Water type	**Kinetin**	**Cultivars**				**Kinetin ×water**	**Water type**
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	0.000150 cde	0.000133 e-f	0.000137 efg	0.000133 e-f	0.000138 c	0.000151 a
	Kinetin	0.000180 a	0.000163 abc	0.000157 cd	0.00016 bc	0.000165 a	
Well	With out Kinetin	0.000103 i	0.000123 f-h	0.00012 ghi	0.000117 hi	0.000116 d	0.000134 b
	Kinetin	0.000177 ab	0.000163 abc	0.00014 def	0.000133 e-f	0.000153 b	
Without kinetin×cultivar		0.000127 d	0.000128 d	0.000128 d	0.000125 d	Kinetin	
Kinetin×cultivar		0.000178 a	0.000163 b	0.000148 c	0.000147 c	Without kinetin	Kinetin
Cultivar×river water		0.000165 a	0.000148 b	0.000147 b	0.000147 b	0.000127 b	0.000159 a
Cultivar×well water		0.000140 bc	0.000143 b	0.000130 cd	0.000125 d		
Cultivar		0.000152 a	0.000146 ab	0.000138 bc	0.000136 c		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 5: Impact of irrigation water and kinetin foliar spray on the CGR of soybean cultivars (gm cm^{-2} day^{-1}) at 60-90 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	0.000123 ef	0.000137 de	0.00013 ef	0.000127 ef	0.000129 c	0.000168 a
	Kinetin	0.000213 a	0.000212 a	0.000200 ab	0.000193 ab	0.000206 a	
Well	With out Kinetin	0.00011 f	0.000113 ef	0.00011 f	0.000117 ef	0.000113 d	0.000145 b
	Kinetin	0.000197 ab	0.000177 bc	0.00016 dc	0.000177 bc	0.000178 b	
Without kinetin×cultivar		0.000117 c	0.000125 c	0.000120 c	0.000122 c	Kinetin	
Kinetin×cultivar		0.000205 a	0.000197 ab	0.00018	0.000185 b	Without kinetin	Kinetin
Cultivar×river water		0.000168 ab	0.000177 a	0.000165 ab	0.000160 abc	0.000121 b	0.000192 a
Cultivar×well water		0.000153 bc	0.000145 cd	0.000135 d	0.000147 cd		
Cultivar		0.000161 a	0.000153 a	0.000150 a	0.000161 a		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 6: Impact of irrigation water and kinetin foliar spray on the CGR of soybean cultivars (gm cm^{-2} day^{-1}) at 90-120 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	With out Kinetin	0.000243 ef	0.000230 f	0.000227 fg	0.000233 f	0.000233 c	0.000267 a
	Kinetin	0.000327 a	0.000287 bc	0.000287 bc	0.000303 b	0.000300 a	
Well	With out Kinetin	0.000207 gh	0.000207 gh	0.000197 h	0.000207 gh	0.000204 d	0.000233 b
	Kinetin	0.000283 bcd	0.000263 ed	0.000227 fg	0.000277 cd	0.000263 b	
Without kinetin×cultivar		0.000225 d	0.000218 d	0.000212 d	0.000220 d	Kinetin	
Kinetin×cultivar		0.000305 a	0.000275 b	0.000257 c	0.00029 ab	With out Kinetin	Kinetin
Cultivar×river water		0.000285 a	0.000258 bc	0.000257 bcd	0.000268 b	0.000219 b	0.000282 a
Cultivar×well water		0.000245 cde	0.000235 e	0.000212 f	0.000242 ed		
Cultivar		0.000265 a	0.000247 b	0.000234 c	0.000255 ab		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 7: Impact of irrigation water and kinetin foliar spray on the NAR of soybean cultivars (gm cm^{-2} day^{-1}) at 30-60 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	1.26 efg	1.29 efg	1.17 gh	1.20 gh	1.23 c	1.40 a
	Kinetin	1.69 a	1.51 bcd	1.53 bc	1.58 ab	1.58 a	
Well	With out Kinetin	1.13 h	1.20 hg	1.35 e-g	1.25 hg	1.23 c	1.34 b
	Kinetin	1.55 abc	1.42 cde	1.41 c-f	1.42 cde	1.45 b	
Without kinetin×cultivar		1.20 c	1.24 c	1.26 c	1.22 c	Kinetin	
Kinetin×cultivar		1.62 a	1.46 b	1.47 b	1.50 b	Without kinetin	Kinetin
Cultivar×river water		1.48 a	1.40 ab	1.35 b	1.39 ab	0.000127 b	0.000159 a
Cultivar×well water		1.34 b	1.31 b	1.39 ab	1.33 b		
Cultivar		1.41 a	1.35 a	1.37 a	1.36 a		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 8: Impact of irrigation water and kinetin foliar spray on the NAR of soybean cultivars (gm cm^{-2} day^{-1}) at 60-90 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	Without Kinetin	1.90 def	1.80 ef	1.94 def	1.77 efg	1.85 bc	2.21 a
	Kinetin	3.20 a	2.36 bcd	1.94 def	2.77 ab	2.57 a	
Well	With out Kinetin	1.93 def	1.49 g	1.54 fg	1.63 fg	1.65 c	1.86 b
	Kinetin	2.57 bc	2.21 cde	1.26 g	2.27 b-d	2.08 b	
Without kinetin×cultivar		1.92 cd	1.65 d	1.74 d	1.70 d	Kinetin	
Kinetin×cultivar		2.88 a	2.28 bc	1.60 d	2.50 ab	Without kinetin	Kinetin
Cultivar×river water		2.55 a	2.08 bc	1.94 bc	2.27 ab	1.75 b	2.32 a
Cultivar×well water		2.25 ab	1.85 c	1.40 c	1.95 bc		
Cultivar		2.40 a	1.96 b	1.67 c	2.11 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

Supplement 9: Impact of irrigation water and kinetin foliar spray on the NAR of soybean cultivars (gm cm^{-2} day^{-1}) at 90-120 DAP.

Water type	Kinetin	Cultivars				Kinetin×water	Water type
		Shaima	Laura	Dee	Lee		
River	With out Kinetin	2.01 bcd	1.77 c-f	1.75 def	1.77 c-f	1.83 b	2.01 a
	Kinetin	2.38 a	2.17 ab	2.10 ab	2.20 abc	2.21 a	
Well	With out Kinetin	1.93 b-e	1.49 f	1.54 f	1.63 ef	1.65 c	1.79 b
	Kinetin	2.37 a	1.81 c-f	1.63 ef	1.90 b-e	1.93 b	
Without kinetin×cultivar		1.97 b	1.63 c	1.65 c	1.70 c	Kinetin	
Kinetin×cultivar		2.37 a	1.99 b	1.86 bc	2.05 b	With out Kinetin	Kinetin
Cultivar×river water		2.19 a	1.97 abc	1.93 bc	1.99 abc	1.74 b	2.07 a
Cultivar×well water		2.15 ab	1.65 d	1.59 d	1.77 cd		
Cultivar		2.17 a	1.81 b	1.76 b	1.88 b		

* Similar characters mean no significant difference according to the Duncan polynomial test at probability level 0.05

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