Interactive Effects of Agrivoltaic Shading, Irrigation, and Biofertilizers on the (N, P, K, Na) of Lettuce Leaves (Lactuca sativa L(.

Manar Ali Khudhair Mohammed R. Sahib Hadi A. AL-Agele
1E-mail: manar.ali@agre.uoqasim.edu.iq
2E-mail: mohammad.radhi@agre.uoqasim.edu.iq
3E-mail: hadi.abdulameer@agre.uoqasim.edu.iq
3-1Department of Horticulture, College of Agriculture, University of Al-Qasim Green, Iraq.

Abstract

The agrivoltaic system is among the most effective methods for achieving sustainability by maximizing the use of agricultural land for both crop production and electricity generation. This system reduces water consumption by shading soil and plants, thereby minimizing evaporation and retaining soil moisture for longer periods compared to open-field cultivation. This study aimed to investigate the effects of shaded versus unshaded cultivation, irrigation levels (100% and 50%), and biofertilizer application on the concentration of (N , P , K , Na) in plant leaves. The results indicated that shaded and unshaded cultivation significantly increased leaf contents of potassium and sodium. Biofertilizer, composed of a mixture of Trichoderma and mycorrhiza, significantly enhanced sodium concentrations in leaves. Irrigation levels, however, showed no significant effects on leaf contents of nitrogen, phosphor, potassium and sodium . The interaction of shaded cultivation with biofertilizer resulted in significant increases in nitrogen, phosphor, potassium, and sodium content. Similarly, the interaction of shaded cultivation with irrigation significantly enhanced nitrogen, phosphor, sodium, and potassium concentrations. Moreover, the interaction between irrigation and biofertilizer showed significant improvements in nitrogen, sodium and potassium contents. Lastly, the three-way interaction among shading, irrigation, and biofertilizer had significant effects on all studied parameters, leading to increased concentrations of nitrogen, phosphor, potassium, and sodium in leaf tissues.

Keywords: Agrivoltaic system, bio-fertilization, drip irrigation, deficit irrigation, (N, P, K, Na(

Introduction

Lettuce (Lactuca sativa L.) is a widely cultivated leafy vegetable valued for its low caloric and fat content. It thrives in cool seasons, with optimal growth temperatures of 23°C during the day and 7°C at night. Due to its perishable nature, lettuce must be cooled immediately after harvest. It is rich in essential vitamins and pigments like chlorophyll but is prone to nitrate accumulation, which increases with nitrogen and inversely correlates with carbohydrate (1; 2.(

Agriculture forms the backbone of many economies, providing food for growing populations. However, climatic factors significantly influence food production, creating imbalances in ecological systems. By 2050, rapid population growth is projected to exacerbate food shortages, necessitating sustainable agricultural systems to protect the environment and enhance food production (3; 4). Sustainable agricultural systems are adaptable to environmental variability and incorporate practices to conserve natural resources such as soil, plants, and water. Techniques like drip irrigation and biofertilization have proven effective in minimizing water usage (5; 6). Biofertilization reduces reliance on chemical fertilizers, whose excessive use has adversely affected soil and plant health This approach enhances plant

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growth, environmental resilience, and resistance to diseases while improving crop quality (7.(

Biofertilizers also facilitate root absorption of vital nutrients such as nitrogen, phosphorus, sodium, and potassium, which are essential for optimal plant growth (9). Another sustainable method is drip irrigation, which delivers water directly to the root zone through emitters placed on or below the soil surface, ensuring optimal soil moisture without waterlogging (8). Agrivoltaic systems, emerging in land-constrained regions, integrate solar panel installations with crop cultivation, enabling dual production of electricity and crops (10). These systems reduce evaporation and transpiration, cooling plants and conserving water resources (11.(

Given Iraq's challenges of limited electricity and low awareness of agrivoltaic systems, this study introduces wooden structures mimicking solar panels to evaluate their effects on lettuce cultivation and its chemical properties

Study Objectives

The study aimed to assess:

.1 The effects of shaded and unshaded cultivation.

.2 Irrigation levels (100% and 50%.(

.3 Biofertilizer application.

.4 The interactions among these factors on the chemical properties of lettuce leaves.

Material and method

Experiment Location

The experiment was conducted in the guidance farm in Al-Mahnawiya / Babylon, The field was plowed and divided into experiment plots (2m*1m) (length, and width) beneath simulated solar panels and a control area. The simulated agrivoltaic systems were built in the extension farm from wood and covered from the top by blue plastic which does not allow sunlight to penetrate through it to the soil. The dimensions of the agrivoltaic systems were designed 12m*2.5m*1.5m) (length, width, and height) with an angle of 30 degrees.

The aggregated soil samples were taken from four randomized sites at a depth of 30 cm and were analyzed to determine their chemical and physical properties. The samples were air-dried and after that, they were ground and sieved using a 2 mm mesh sieve. The soil samples were analyzed to determine their chemical and physical properties as shown in Table (1) and the weather data shows in Table (2). Bio-fertilizers composed of a mixture of Trichoderma and Mycorrhiza were added two times during the growing season.

Table 1. Chemical and Physical Properties of Field Soil.

pH	Ec (ds/m)	N (mg/kg)	P (mg/kg)	K (mg/kg)	Ca (meq/L)	Mg (meq/L)	Na (meq/L)	Hco^{-3} (meq/L)	Co^{3} (meq/L)	Cl (meq/L)
7.81	6.45	152.6	85.6	0.9	31.2	59	31.3	8.8	0	42.8

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Organic matter (gm kg^{-1})	Black density (gm/cm^3)	Soil Texture	Field capacity (%)	Wilting point (%)
0.56	1.3	Silty Clay Loam	40	21

Table 2. The weather data during growing season

Date	Ave. Temp. (C°)	Rainfall (mm)	Wind speed (m/sec)	Relative Humidity (%)
15/10-15/11	32	5.1	72.40	1.79
16/11- 15/12	20	51.1	56.91	1.29

A drip irrigation system was installed before planting. The plants were planted in two rows within each plot, the distance between the rows is 30 cm, and 20 cm between individual plants within a row. The lettuce grown in the agrivoltaic system and control field (open area) were each broken into treatments, respectively. These treatments combined a fertilizer application level and an irrigation level. The plots are treated with biofertilizers at one of the two levels (0, 100%) and one of two levels of irrigation 100% and 50%. The experimental plots were divided into treatments and replicates and each treatment was replicated six times in both the shaded and control areas for a total of 24 plots in each. The biofertilizer was prepared at the Ministry of Science and Technology, Agricultural Research Department, and was carried on peat moss. The Trichoderma asperellum concentration was 10^9 C.F.U and mixed with Mycorrhiza mosess before being added to the plants using the compost tea drenching method. The biofertilizer was applied two times, the first was added one month after planting, and a second application was added two weeks after the first. The vegetative traits were taken from 10 plants for all the individual measurements.

Result and dissection

Nitrogen Content in Leaves(%)

Table 3 reveals no significant effects of biofertilizer, irrigation, or light as individual factors on Nitrogen content. However, interactions revealed:Significant interactions included:

.1 Biofertilizer and light interaction: The highest nitrate content (6.41) was recorded in shaded plants with the second fertilization level, while the lowest (5.67) was in light-exposed plants with the second fertilization level.

.2 Biofertilizer and irrigation interaction: The highest value (6.09) occurred in plants under the second fertilization level with 100% irrigation, while the lowest (5.61) was in plants with the first fertilization level under 100% irrigation.

.3 Light and irrigation interaction: The highest nitrate content (6.19) was found in shaded plants with 50% irrigation, whereas the lowest (5.57) was in light-exposed plants with 50% irrigation.

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.4 Three-way interaction: The maximum (6.42) occurred in shaded plants with the second fertilization level under 100% irrigation, while the minimum (5.47) was observed in light-exposed plants with the first fertilization level under 100% irrigation.

Table (3) The effect of shade cultivation, non-shade cultivation, irrigation factor, biofertilizer factor and their interactions on Nitrogen (%)

Treatment		**F0**	**F1**	**S*I**
S1	$I_{0.5}$	**5.97**	**6.41**	**6.19**
	I_1	**5.76**	**6.42**	**6.09**
S2	$I_{0.5}$	**5.93**	**5.58**	**5.57**
	I_1	**5.47**	**5.76**	**5.62**
LSD(0.05)		**0.56**		**0.40**
				S
S*F	**S1**	**5.86**	**6.41**	**6.14**
	S2	**5.70**	**5.67**	**5.68**
LSD(0.05)		**0.44**		**N.S**
F		**5.78**	**6.04**	
LSD(0.05)		**N.S**		
				I
F*I	$I_{0.5}$	**5.95**	**5.99**	**5.97**
	I_1	**5.61**	**6.09**	**5.85**
LSD(0.05)		**0.37**		**N.S**

Phosphor Content in Leaves(%)

Table 4 reveals no significant effects of biofertilizer, irrigation, or light as individual factors on Phosphor content. However, interactions revealed:

Interactions between factors highlighted:

.1 Biofertilizer and light interaction: The maximum Phosphor content (0.85) occurred in light-exposed plants with the first fertilization level, while the minimum (0.39) was in shaded plants with the second fertilization level.

.2 Light and irrigation interaction: light-exposed plants with 100% irrigation had the highest content (0.57), while the lowest (0.39) was in shaded plants with 100% irrigation.

.3 Three-way interaction: The highest value (0.58) was observed in light-exposed plants with the first fertilization level under 100% irrigation, while the lowest (0.38) was recorded in shaded plants under the second fertilization level with 100% irrigation.

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Table (4) The effect of shade cultivation, non-shade cultivation, irrigation factor, biofertilizer factor and their interactions on Phosphor (%)

Treatment		F0	F1	S*I
S1	$I_{0.5}$	0.40	0.41	0.40
	I_1	0.4	0.38	0.39
S2	$I_{0.5}$	0.57	0.45	0.51
	I_1	0.58	0.56	0.57
LSD(0.05)		0.09		0.08
				S
S*F	S1	0.40	0.39	0.39
	S2	0.85	0.50	0.54
LSD(0.05)		0.08		N.S
F		0.49	0.45	
LSD(0.05)		N.S		I
F*I	$I_{0.5}$	0.49	0.43	0.46
	I_1	0.49	0.47	0.48
LSD(0.05)		N.S		N.S

Potassium Content in Leaves(%)

Table 5 shows no significant effects of biofertilizer or irrigation on Potassium content. However, light conditions significantly affected Potassium levels, with the highest (21.62) observed in shaded plants and the lowest (17.29) in light-exposed plants.

Significant interactions included:

.1Biofertilizer and light interaction: The highest Potassium content (22.50) was recorded shaded plants with the second fertilization level, while the lowest (17.47) was in light-exposed plants with the first fertilization level.

.2Biofertilizer and irrigation interaction: The highest value (21.22) occurred in plants under the second fertilization level with 100% irrigation, while the lowest (18.57) was in plants with the first fertilization level under 100% irrigation.

.3Light and irrigation interaction: The highest Potassium content (21.77) was found in shaded plants with 50% irrigation, whereas the lowest (17.29) was in light-exposed plants with 50% irrigation.

.4Three-way interaction: The maximum (23.63) occurred in shaded plants with the second fertilization level under 100% irrigation, while the minimum (17.13) was observed in light- exposed plants with the first fertilization level under 50% irrigation .

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Table (5) The effect of shade cultivation, non-shade cultivation, irrigation factor, biofertilizer factor and their interactions on Potassium (%)

Treatment		F0	F1	S*I
S1	$I_{0.5}$	22.17	21.37	21.77
	I_1	19.33	23.63	21.48
S2	$I_{0.5}$	17.13	17.39	17.53
	I_1	17.8	18.8	18.3
LSD(0.05)		3.18		2.66
				S
S*F	S1	20.75	22.50	21.62
	S2	17.47	18.37	17.29
LSD(0.05)		2.31		2.87
F		19.11	20.43	
LSD(0.05)		N.S		
				I
F*I	$I_{0.5}$	19.65	19.65	19.65
	I_1	18.57	21.22	19.89
LSD(0.05)		2.50		N.S

Sodium Content in Leaves(%)

Table 6 shows a significant effect of biofertilizer on Sodium content. The highest value (198.2) was found in plants under the first fertilization level, while the lowest (158.1) was under the second fertilization level. Light also significantly influenced Sodium content, with shaded plants recording the highest (215.5) and light-exposed plants the lowest (167.7). Irrigation had no significant effect as an individual factor.Significant interactions included:

.1 Biofertilizer and light interaction: The highest Sodium content (216.8) was recorded in shaded plants with the first fertilization level, while the lowest (155.9) was in light-exposed plants with the second fertilization level.

.2 Biofertilizer and irrigation interaction: The highest value (214.3) occurred in plants under the first fertilization level with 100% irrigation, while the lowest (181.3) was in plants with the second fertilization level under 100% irrigation.

.3Light and irrigation interaction: The highest Sodium content (223.5) was found in shaded plants with 100% irrigation, whereas the lowest (163.4) was in light-exposed plants with 50% irrigation.

.4Three-way interaction: The maximum (235.1) occurred in shaded plants with the first fertilization level under 100% irrigation, while the minimum (150.8) was observed in light-exposed plants with the second fertilization level under 100% irrigation .

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Table (6) The effect of shade cultivation, non-shade cultivation, irrigation factor, biofertilizer factor and their interactions on Sodium (%)

Treatment		F0	F1	S*I
S1	$I_{0.5}$	198.5	216.7	207.6
	I_1	235.1	211.8	223.5
S2	$I_{0.5}$	165.8	161	163.4
	I_1	193.3	150.8	172.1
LSD(0.05)		18.88		16.41
				S
S*F	S1	216.8	214.3	215.5
	S2	179.6	155.9	167.7
LSD(0.05)		15.44		19.91
F		198.2	158.1	
LSD(0.05)		9.38		
				I
F*I	$I_{0.5}$	182.2	188.9	185.5
	I_1	214.2	181.3	197.8
LSD(0.05)		13.6		N.S

Table (5) showed a significant increase in the potassium content of the leaves, but it was not toxic, as the percentage, if it was greater than 50 mg/g is toxic, but its percentage was (21.62) in shade area and (17.29) in light area , and thus this percentage is considered normal and not harmful to human health, unlike in Table (6), where the percentage in the leaves was very high, whether in plants grown in the shade and light area (12;13;14;15.(

Also, the significant increase shown in Table (6) may be due to the soil containing a high percentage of sodium, and this increase may be due to the fact that most agricultural lands have high sodium content and excessive concentrations, so many farmers are turning to finding strains that can withstand harmful abiotic conditions (16.(

While the irrigation factor at its levels (50-100%) did not show any significant effect on all measured indicators.

Conclusion

The results of the study showed that output or (N ,P, K, Na) was not considerably affected by reduced irrigation (50% of full irrigation), and the result of bio fertilizer was not considerably effected on (N, P, K .(

Recommendations

This suggests that using deficit watering is efficient for lettuce growth and won't have a detrimental impact on lettuce yield..

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