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Effect of Seed Priming and Biofertilization Treatments on Vegetative Growth Characters of Soybean under Water Stress Conditions

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ABSTRACT

Two field experiments were conducted at the experimental farm, Faculty of Agriculture, Mansoura University, Dakahlia Governorate, Egypt during 2022 and 2023 seasons to improving growth of soybean plants using seed priming (without, hydropriming, calcium chloride, humic acid and seaweed extract) and biofertilization (without, inoculation with *Rhizobium japonicum*, Mycorrhiza and *Rhizobium japonicum* + Mycorrhiza) treatments under water stress conditions (irrigation levels as 100, 80 and 60 as a ratio from water requirement). Every irrigation level was tested independently. Each irrigation level experiment was conducted in three replications using a strip-plot design. The highest values of all examined growth parameters were obtained in both seasons when water stress treatment was not applied, i.e., when irrigation level was set at 100% of water need (2818 m3/fed). The highest values of all the development characteristics under study were obtained in both seasons when seeds were primed in calcium chloride ($CaCl_2$) at a rate of 6 g/L. Seed inoculation with *Rhizobium japonicum* besides Mycorrhiza exceeded other biofertilization treatments and produced the highest values of all studied growth characters in both seasons. In order to save irrigation water at the same time maintaining highest growth parameters, it could be recommended that irrigation soybean plants at the level of 80 % from water requirement (2254.4 m^3/fed) and priming seed in $CaCl_2$ at 6 g/L besides inoculation seeds with *Rhizobium japonicum* in addition inoculation with Mycorrhiza under the local climate of Egypt's Dakahlia Governorate's Mansoura district.

Keywords: Soybean, water stress, irrigation levels, seed priming, biofertilization.

INTRODUCTION

For both humans and animals, soybeans [*Glycine max* (L.) Merr.] is an essential source of protein and edible vegetable oil. According to IITA (1993), it has more than 40% protein, 20% edible vegetable oil, 30% Carbohydrates, 10% total sugars, and 5% ash. With an amino acid composition that is almost identical to that of meat proteins, soybean protein is of excellent nutritional grade. Because it is cholesterol-free and high in essential fatty acids, soybean oil is being used more and more in the manufacturing of biodiesel (Acikgoz *et al*., 2009). Soybeans are considered a relatively new crop in Egypt's agricultural industry, helping to bridge the gap between oil and protein and easing the lack of oil output. But soybeans have had trouble establishing their right place.

It is commonly known that using the right agronomic techniques may improve the production of any crop and allow for vertical development. Furthermore, agronomic procedures including seed priming and biofertilization treatments have a critical role in reducing water stress and enhancing soybean development, productivity, yield components, and seed quality.

One of the major reasons limiting Egypt's agricultural output and decreasing the effectiveness of dryland farming is drought. Thus, it is achievable to produce in semi-arid environments by selecting and using drought-tolerant crops in conjunction with specialist crop enhancement techniques. For maximum yield, soybeans need enough water at every step of their physiological development. But just like other crops, there are essential growth phases where production is significantly impacted by inadequate soil moisture. Several physiological processes (includes respiration, turgor maintenance, nitrogen fixation, ion uptake, transport and assimilation, growth regulator movement, photosynthesis, and the translocation of carbohydrates.) as well as shoot characteristics are adversely affected by water stress during soybean growth stages (Fageria *et al*., 2006). Du and associates (2020) found that the effects of drought stress decreased the biomass of soybean shoots, the photosynthetic rate of leaves, and the overall growth by 63.93%, 33.53%, and 41.65%, respectively. According to Dong *et al*. (2024), one of the main factors reducing soybean development in arid and semi-arid locations is drought stress. According to Petcu *et al*. (2024), water stress reduced the amount of chlorophyll in soybean plants and impeded growth features. According to Yavas *et al*. (2024), drought stress impairs growth by interfering with the biochemical and physiological functions of the plant, which lowers photosynthesis. In conclusion, soybean growth is negatively impacted by drought stress, and its impacts during critical growth periods are a major factor in the reduction of seed output.

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A technique called "seed priming" alters the physiological and biochemical characteristics of seeds to improve characteristics that increase their resistance to drought stress. Hydration and dehydration cycles cause this process, which is also known as substantial physiological remodeling. Numerous physicochemical alterations take place during priming, changing the protoplasmic properties and increasing the embryo's and its related structures' physiological activity. Consequently, a stronger, more effective root system and enhanced cell wall flexibility allow seeds to absorb more water (Krishnasamy and Srimathi, 2001). In order to solve problems with poor crop emergence and establishment under difficult environmental conditions, water priming has been suggested (Dinssa, 2020). According to Aminu *et al.* (2022), priming seeds for eight hours greatly increased stand count and plant height in soybean.

Calcium chloride ($CaCl_2$) seed priming is a useful technique for lessening the effects of stress on plants. Because of its crucial function in a variety of defense mechanisms brought on by environmental stressors, calcium ions (Ca2+) have drawn a lot of attention and offer plants protection in harsh environments (Hironari and Takashi, 2014). According to Chavan *et al.* (2014), seed priming increased plant height and branch count in soybeans in general, with $CaCl_2$-priming showing the biggest effects. According to Zaki *et al.* (2018), soybean seeds primed with $CaCl_2$ outperformed those primed with water in terms of seedling growth characteristics. Calcium chloride seed priming raises the amount of iron, calcium, magnesium, and potassium while lowering sodium build-up, according to Ben Youssef *et al.* (2024).

Humic acid, a water-soluble organic acid, is found naturally in soil organic matter. It is generally recognized that humic substances (HS) improve the number of bacteria and soil structure, as well as mechanisms that promote plant development, enhance nutrient uptake, and boost yield. It has been demonstrated that these compounds have both direct and indirect effects on plant development. Higher rates of photosynthesis and respiration, enhanced protein synthesis, and plant hormone-like activity, among other biochemical processes occurring at the cell wall, membrane, or cytoplasm levels, are examples of the direct effects of humic acid molecules. By (i) increasing the population of beneficial microbes and other soil microbials, (ii) improving soil structure, and (iii) Humic substances improve the soil's ability to exchange cations and buffer pH, which in turn improves soil fertility. (Akinremi *et al*., 2000). Canellas *et al.* (2020) observed that humic chemical priming is a promising strategy for crop stress management and plant stress physiology. Weerasekara *et al*. (2021) discovered that 0.2 g/L humic acid seed priming for five hours enhanced the vigor of soybean seeds that had just slightly degraded, resulting in greater emergence and more consistent field establishment. Rao *et al*. (2024) reported that chemical priming with a combination of humic acid and salicylic acid was the most effective treatment for improving plant stand establishment under stress conditions.

seaweed extract contains three major classes of plant hormones, giberellins, cytokinins, and auxins. Additionally, 10% potassium salts of amino acids are added to it for enrichment. This preparation increases respiration rates and root growth, improves the uptake and translocation of macro- and micronutrients inside plants, and contributes to photosynthesis and other metabolic activities. It increases flowering and fruit set, boosts soil water-holding capacity, helps maintain ideal soil pH, and favorably affects plant resilience to stress (Bai *et al.*, 2007). (Matysiak *et al*., 2010). Makhaye *et al.* (2021) reported that seed priming with seaweed extract may have a carry-over effect, benefiting seedling growth as well as biochemical parameters. Arab *et al*. (2022) noted that applying seaweed extract as a seed pretreatment could mitigate the negative effects of aging and significantly enhance the physiological and agronomic traits of soybean. Oliveira *et al*. (2024) found that seed priming with seaweed extract improved growth characteristics, chlorophyll index, and biomass of soybean plants.

The objective of biofertilizer technologies is to improve and strengthen the soil profiles' inherent nutrient processing processes. These technologies' inoculants need to be able to adjust to the local environmental conditions at the application site in order to limit the environmental damage that mineral fertilizers cause and lower the expenses related to them.

Bacteria such as *Rhizobium* in the nodules of legume plants are responsible for fixing nitrogen from the atmosphere, and they are particularly beneficial in soils that have not previously supported soybean cultivation. In Egypt, where soils are often low in organic matter, the response to fertilizers tends to be limited due to the rapid fixation of nutrients. In these conditions, inoculating soil with microorganisms like *Rhizobium japonicum* can be advantageous. To maximize effectiveness, it is important to establish a high level of inoculation with *Rhizobium japonicum* (Jaga and Sharma, 2015). According to Rabiul *et al.* (2020), applying *Rhizobium* inoculants enhances plant growth. Islam *et al.* (2021) found that *Rhizobium* inoculation significantly impacts the vegetative growth and nodulation of soybean. Purwani and Ginting (2023) noted that increasing soybean yields, enhancing the effectiveness of inorganic fertilizers, and fostering environmental sustainability may all be achieved with the use of biofertilizers. According to Korobko *et al.* (2024), soybeans are a beneficial crop for contemporary crop rotations because of their ability to fix atmospheric nitrogen. Nitrogen-fixing and phosphate-mobilizing bacteria have been shown to improve the capacity of soybean cultivars to fix nitrogen when applied to seeds.

Mycorrhiza is a promising biotechnology technique that can improve plant uptake of phosphorus and increase its availability in soil. In addition to enhancing nutrient absorption, mycorrhizal fungi accelerate photosynthesis, enhance osmotic adjustment under salinity and drought stress, promote resistance to pests and soil-borne illnesses, and stimulate the production of growth-regulating chemicals. (Al-Karaki, 2006). It has also been demonstrated that mycorrhizal symbiosis enhances the uptake of nutrients including copper, zinc, and phosphorus in plants under drought stress (Ardakani *et al*., 2009). Arbuscular mycorrhizal fungus (AMF) inoculation increased biomass output under a variety of edaphoclimatic settings, according to Stoffel *et al*. (2020). Arbuscular mycorrhizal fungi, according to Wen *et al*. (2023), recruit rhizobacteria that support plant growth and modify the root-associated microbiome in a host-dependent manner to enhance soybean growth and stress tolerance. According to Subaedah *et al.* (2024), mycorrhizal treatment (at 10 g/plant) greatly enhanced the growth properties of soybeans.

Studying the effects of seed priming and biofertilization treatments on soybean growth parameters under water stress conditions in the El-Mansoura district of the Dakahlia Governorate, Egypt, was the aim of the present research.

MATERIALS AND METHODS

Two field experiments aimed to improve soybean growth using seed priming and biofertilization treatments under water stress conditions were conducted at the Experimental farm, Faculty of Agriculture, Mansoura University, Dakahlia Governorate, Egypt, during the two consecutive summer seasons of 2022 and 2023.

Irrigation levels as a ratio from water requirement, each irrigation level was performed in separate experiment and separated by deeper channels and polyethylene sheets. Every experiment of irrigation level was carried out in strip-plot design in three replications.

The studied water stress conditions *i.e.* irrigation levels as 100, 80 and 60 % from water requirement (2818 m^3/fed) was performed according to Adam *et al.* (2014). The number of irrigations for soybean throughout their life in the study area was 8 Irrigations; the amount of water per each irrigation was equal to 352.25 m^3/fed for normal irrigation (100 % from water requirement), 281.80 m^3/fed for 80 % from water requirement and 211.35 m^3/fed for 60% from water requirement. The same amount of water was added to the first irrigation (sowing irrigation) and the second irrigation (Mohayah irrigation) for all irrigation levels under study, and the water stress (80 and 60 % from water requirement) was applied starting from the third irrigation.

The vertical plots were occupied with the seed priming treatments *i.e.* without seed priming ,*i.e;* dry seed (control treatment), seed priming in distillated water ,*i.e;* hydropriming seed, seed priming in calcium chloride ($CaCl_2$) at rate 6 g/L, seed priming in humic acid at rate 2 g/L and seed priming in seaweed extract at rate 8 g/L.

Before seed priming, soybean seeds were surface sterilized for five minutes in a 1.5% sodium hypochlorite solution (NaOCl). They were then rinsed three times with distilled water. Sterilized seeds were then primed in the various solutions stated above. Samples of five kilograms of soybean seeds were soaked for seven hours in the priming solutions (hydropriming, calcium chloride CaCl2, humic acid and seaweed extract) at the rates mentioned above. Before being stored in a polyethylene bag at 4 °C and 30 ±2% relative humidity until the planting date, the primed seeds were left in the shade for three days to return to their initial moisture content. The source of the calcium chloride employed in this study was El-Gomhoria Company. However, the seaweed extract and humic acid utilized in this study were supplied by Al-Hayah for Agricultural Projects and produced by United for Agricultural Development. The humic acid utilized in this investigation was Uni-humic, which includes 18.5 % high purity humic acid, 1.5% folic acid 0.5 % K2O and 0.5-1.0 % micronutrients.

The horizontal plots were assigned to biofertilization treatments *i.e.* without inoculation with biofertilizers (control treatment), seed inoculation with *Rhizobium japonicum*, inoculation with Mycorrhiza and seed inoculation with *Rhizobium japonicum* + Mycorrhiza.

The primed soybean seeds were inoculated with *Rhizobium japonicum* by preparing sugar solution (dissolving 250 g sugar/liter water), empty the contents of the nodulating bacteria bags (2-3 bags/fed) and mixing well with the previously prepared sugar solution, placing the seeds on a clean polyethylene sheet in a shaded place and spraying with the mixture of nodules and the previously prepared sugar solution and mixing well until homogeneous and leave its for about 15 minutes, then sowing and irrigation immediately.

The Mycorrhiza was added to soil before sowing irrigation at the rate of 5 g/hill as side-dressing near soybean hills. *Rhizobium japonicum* bacterial strain and mycorrhiza were obtained from Biofertilization Unit, Soil and Water Research Institute, Agricultural Research Cen, Giza, Egypt.

Using the method described by Page *et al.* (1982), soil samples were randomly selected from the experimental field area and taken between 0 and 30 cm below the soil surface prior to soil preparation and recorded in Table 1.

Table 1. The mechanical and chemical analyses of the experimental soil sites during 2022 and 2023 seasons.

Soil properties	2022 season	2023 season
Mechanical analysis:		
Clay %	19.51	19.45
Silt %	31.18	31.15
Sand %	49.31	49.40
Texture	Clayey	Clayey
Chemical analysis:		
Organic matter%	3.12	3.15
Bulk density. (g cm$^{3)}$	1.32	1.35
EC, dS m^{-1} (25 °C)	1.63	1.65
PH	7.75	7.80
CaCo$_{3}$ %	2.54	2.55
Available nitrogen, ppm	19.00	19.50
Available potassium, ppm	325.00	320.50
Available phosphorus, ppm	7.00	7.50

Each experimental basic unit had five ridges, each measuring 3.5 meters in length and 60 centimeters in width, for a total area of 10.5 m2 (1/400 fed). Wheat (*Triticum aestivum* L.) was the winter crop that came before in both seasons.

Two ploughs, leveling, compaction, and ridging were used to prepare the experimental field, which was then separated into experimental units (10.5 m2). When preparing the soil, 150 kg/fed of calcium superphosphate (15.5% P2O5) was added.

On both sides of ridges that were 60 cm wide, soybean seeds were immediately planted in hills, 20 cm apart, yielding a plant density of 140,000 plants per feed. The first season was sown on May 8th, while the second season was sown on May 5th. Two healthy seedlings per hill were left after full germination after the excess plants were pruned 21 days after sowing. Hand hoeing was done every 21 days, generally before irrigation, to keep weeds under control. Applying nitrogen and potassium fertilizers in equal amounts as urea (46.0% N) and potassium sulfate (48% K_2O) at rates of 60 kg N per fed and 48 kg K_2O per fed was done prior to the second and third irrigations. In accordance with the Ministry of Agricultural and Land Reclamation's guidelines, other traditional methods of growing soybeans were used.

The vegetative growth samples were taken at random from five guarded plants from the two inner ridges of the experimental unit after 60 days from sowing to estimate the following growth parameters:

1. Plant height (cm). From the soil's surface to the top of the main stem, it was measured for every plant in the samples.
2. Number of branches/plant.
3. Number of leaves/plant.
4. Leaf area/plant (cm^2). For leaf area measurements, the disc method was followed using 10 disks of 1 cm diameter, according to Vivekanandan *et al.*, (1972).

$$\text{Leaf area/plant (LA)} = \frac{\text{Wa} \times \text{A}}{\text{Wb}}$$

Where: **Wa = Weight of all leaves + discs.**
A = Area of discs (cm^2).
Wb = Weight of 10 discs.

5. Pigments involved in photosynthesis (Chlorophyll a, chlorophyll b, total chlorophyll and carotenoids) were extracted from fresh fourth leaf 60 days following the Sims and Gamon (2002) methods of sowing. Pigments were extracted using a cold acetone:50 mM Tris buffer solution at pH 7.8 (80:20) (v/3). Using a spectrophotometer, the absorbance of the supernatant at 470, 537, 647, and 663 nm was measured after centrifugation. Chlorophyll a, chlorophyll b, total chlorophyll and carotenoids results are expressed as mg/g fresh weight.
6. Fresh weight of shoot (g): The fresh weight of shoot was taken from each plant of the samples for recording.
7. Dry weight of shoot (g): The dry weight of the shoot was taken from each plant of the samples, then the same samples were sun dried and later dried in hot air oven for about 48 hours at 70º C. When it was dried, weight of the sample was taken for recording.
8. Fresh weight of roots (g): The fresh weight of the roots was taken was taken from each plant of the samples for recording.
9. Dry weight of roots (g): The dry weight of the roots was taken from each plant of the samples, then the same samples were sun dried and later dried in hot air oven for about 48 hours at 70º C. When it was dried, weight of the sample was taken for recording.
10. Number of nodules/plants: The nodules number was obtained by uprooting plants carefully at random from each plot. Then, the roots were carefully washed by water to avoid losing root nodules and the nodules from the root of each plant of the samples were separately collected and counted.
11. Fresh weight of nodules (g): After obtaining the nodules, they were weighed for recording.
12. Dry weight of nodules (g): The nodules were dried in hot air oven for about 48 hours at 70° C to remove the moisture content from the nodule, nodules were weighed to obtain the nodule dry weight.

For each experiment (irrigation levels), the acquired data were subjected to an ordinary analysis of variance (ANOVA) using the strip-plot design. A combined analysis between irrigation experiments was then conducted, using the methodology described by Gomez and Gomez (1984). Error variance homogeneity was tested using Bartlett's test. Using the least significant differences test (LSD), as outlined by Snedecor and Cochran (1980), differences between treatment means were compared. The statistical analysis was carried out using analysis of variance approach (ANOVA) by the "MSTAT-C" computer software package.

RESULTS AND DISCUSSION

Effect of irrigation levels:

The results obtained from this study clearly demonstrated that the water stress treatments, represented by irrigation levels of 100%, 80%, and 60% of the water requirement (2818 m³/fed), had significant impacts on various growth parameters. This included plant height, the number of branches and leaves per plant, leaf area per plant, photosynthetic pigments (chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids), as well as the fresh and dry weights of the shoot and root, number of nodules per plant, and the fresh and dry weights of the nodules in both seasons (Tables 2, 4, 6, and 8).

Table 2. Plant height, number of branches and leaves per plant and leaf area per plant of soybean as affected by irrigation levels, seed priming and biofertilization treatments as well as their interactions during 2022 and 2023 seasons.

Characters Treatments	Plant height (cm)		Number of branches/ plant		Number of leaves/ plant		Leaf area/plant (cm^2)	
Seasons	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
A. Irrigation levels (as a ratio from water requirement):								
100 %	101.54	105.32	9.49	11.00	76.59	81.08	11029.0	11675.9
80 %	82.97	86.50	6.14	7.74	53.96	58.46	5871.8	6344.5
60 %	65.07	68.05	3.71	5.25	31.88	36.37	3326.3	3794.1
LSD at 5 %	0.41	0.48	0.20	0.23	0.90	0.96	108.0	112.8
B. Seed priming treatments:								
Without	68.58	71.59	3.83	5.50	34.78	39.08	4401.6	4886.7
Hydropriming	74.71	77.71	4.92	6.48	41.65	46.03	5242.7	5760.1
Calcium chloride	94.45	98.72	8.67	10.22	70.62	75.60	8725.4	9311.5
Humic acid	86.27	89.58	6.72	8.25	56.94	61.38	7092.6	7626.6
Seaweed extract	91.96	95.51	8.11	9.54	66.74	71.09	8249.5	8772.5
LSD at 5 %	0.53	0.63	0.26	0.30	1.32	1.24	139.4	142.3
C. Biofertilization treatments:								
Without	74.98	78.90	4.82	6.27	42.95	47.43	5381.9	5916.0
Rhizobium japonicum	82.12	85.15	6.09	7.57	51.05	55.50	6372.8	6907.0
Mycorrhiza	85.49	88.64	6.94	8.63	57.89	62.14	7196.7	7679.4
Rhizobium japonicum + Mycorrhiza	90.18	93.80	7.95	9.52	64.69	69.48	8018.1	8583.5
LSD at 5 %	0.53	0.55	0.28	0.25	0.87	0.95	107.6	111.4
D- Interactions (F. test):								
A × B	*	*	*	*	*	*	*	*
A × C	*	*	*	*	*	*	*	*
B × C	*	*	*	*	*	*	*	*
A × B × C	*	*	*	*	*	*	*	*

Table 3. Plant height, number of branches and leaves per plant and leaf area per plant of soybean as affected by the interaction among irrigation levels, seed priming and biofertilization treatments during 2022 and 2023 seasons.

Treatments			**Plant height (cm)**		**Number of branches/ plant**		**Number of leaves/plant**		**Leaf area/plant (cm^2)**	
Irrigation levels	**Seed priming**	**Biofertilization**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
100 % of water require-ment	Without	Without	71.94	75.88	3.52	5.41	41.13	45.16	5923.6	6504.0
		Rhizobium (R)	83.70	86.75	5.47	7.27	49.61	54.28	7143.8	7816.3
		Mycorrhiza (M)	85.51	88.62	5.74	7.11	60.64	65.50	8732.1	9432.0
		R + M	93.83	95.62	7.11	8.83	66.32	69.73	9551.0	10041.6
	Hydrop-riming	Without	78.55	82.40	4.55	5.83	44.91	49.50	6467.0	7128.0
		Rhizobium (R)	92.62	97.76	6.71	8.16	64.73	69.16	9321.6	9960.0
		Mycorrhiza (M)	94.98	98.16	8.66	10.27	67.73	70.16	9753.6	10104.0
		R + M	100.94	104.10	9.32	11.00	75.21	79.75	10831.2	11484.0
	Calcium chloride	Without	106.08	112.49	9.77	11.55	79.75	84.50	11484.0	12168.0
		Rhizobium (R)	111.31	114.37	12.38	12.83	92.27	97.50	13287.8	14040.0
		Mycorrhiza (M)	117.47	120.51	13.16	15.16	100.11	104.83	14415.8	15096.0
		R + M	125.95	134.00	15.94	17.16	106.77	110.26	15374.8	15877.9
	Humic acid	Without	97.24	101.15	8.94	9.81	72.87	77.24	10493.7	11122.5
		Rhizobium (R)	103.57	106.45	9.72	10.88	79.19	83.83	11403.8	12072.0
		Mycorrhiza (M)	108.42	109.72	9.84	11.22	80.63	84.77	11611.6	12207.8
		R + M	110.46	113.98	11.26	13.08	90.92	97.11	13093.4	13983.8
	Seaweed extract	Without	102.74	108.00	9.37	11.55	77.69	82.50	11187.8	11880.0
		Rhizobium (R)	109.68	111.42	10.68	12.22	81.19	86.50	11691.8	12456.0
		Mycorrhiza (M)	114.28	117.60	13.04	14.83	95.37	99.83	13733.7	14376.0
		R + M	121.50	127.41	14.69	15.77	104.71	109.50	15078.2	15768.0
80 % of water require-ment	Without	Without	63.14	64.96	2.09	4.00	28.12	31.50	3059.8	3427.2
		Rhizobium (R)	69.39	74.34	4.61	7.14	34.70	39.83	3775.3	4333.8
		Mycorrhiza (M)	71.04	73.45	5.05	6.64	38.93	45.20	4235.5	4591.3
		R + M	74.88	80.31	5.24	7.25	41.24	46.06	4487.2	5012.0
	Hydrop-riming	Without	65.62	68.97	2.96	4.30	34.53	38.61	3757.2	4201.1
		Rhizobium (R)	72.17	75.86	5.18	6.91	39.94	45.83	4345.8	4986.6
		Mycorrhiza (M)	76.33	79.79	5.48	6.81	41.77	46.11	4544.5	5016.7
		R + M	84.12	87.51	5.68	6.69	50.75	56.51	5521.6	6148.6
	Calcium chloride	Without	86.32	90.85	6.20	8.16	55.94	60.89	6086.6	6624.8
		Rhizobium (R)	92.45	93.55	7.02	8.37	65.35	67.16	7110.4	7307.7
		Mycorrhiza (M)	95.66	100.36	8.52	9.91	78.43	81.50	8533.1	8867.2
		R + M	98.73	102.73	9.84	11.83	82.02	89.18	8924.5	9703.5
	Humic acid	Without	81.33	85.23	5.54	6.81	45.76	51.50	4979.0	5603.2
		Rhizobium (R)	85.38	88.55	6.13	8.05	53.66	57.50	5838.2	6256.0
		Mycorrhiza (M)	87.28	94.07	6.43	8.83	59.20	64.16	6441.7	6981.3
		R + M	90.69	90.98	6.98	8.11	62.20	65.61	6768.1	7138.3
	Seaweed extract	Without	84.54	88.19	5.94	7.19	51.30	56.53	5581.8	6150.8
		Rhizobium (R)	89.61	92.52	6.91	8.16	60.31	64.50	6562.4	7017.6
		Mycorrhiza (M)	93.26	95.38	8.02	9.65	75.23	78.77	8185.4	8570.9
		R + M	97.53	102.33	9.08	10.05	79.94	82.28	8697.8	8952.0
60 % of water require-ment	Without	Without	43.59	47.46	1.02	1.27	6.95	10.83	725.7	1130.1
		Rhizobium (R)	50.36	53.18	1.40	2.78	9.30	13.22	970.8	1379.4
		Mycorrhiza (M)	56.07	58.62	1.66	3.83	16.57	22.16	1728.5	2312.4
		R + M	59.53	59.89	3.13	4.55	23.83	25.50	2485.9	2660.1
	Hydrop-riming	Without	48.20	50.66	1.27	2.30	7.62	12.50	795.2	1304.0
		Rhizobium (R)	57.94	59.33	2.37	4.83	19.71	23.68	2056.8	2471.0
		Mycorrhiza (M)	60.69	61.74	3.39	4.91	25.38	28.33	2648.0	2955.7
		R + M	64.33	66.19	3.48	5.73	27.51	32.22	2870.1	3361.5
	Calcium chloride	Without	67.49	71.93	4.11	5.55	36.20	40.16	3776.3	4190.2
		Rhizobium (R)	74.22	77.56	4.57	6.01	41.10	47.50	4287.9	4955.2
		Mycorrhiza (M)	77.06	80.51	5.52	7.22	47.77	52.50	4984.0	5476.7
		R + M	80.73	85.85	6.96	8.83	61.73	71.24	6440.0	7431.7
	Humic acid	Without	61.74	65.71	3.41	5.27	26.70	31.20	2786.0	3254.8
		Rhizobium (R)	67.35	71.03	3.85	4.66	35.61	38.83	3715.2	4051.1
		Mycorrhiza (M)	69.61	72.95	4.11	6.28	36.27	40.73	3784.4	4248.9
		R + M	72.12	75.21	4.43	5.98	40.22	44.09	4196.4	4599.8
	Seaweed extract	Without	66.25	69.61	3.56	5.11	34.75	38.83	3625.1	4051.0
		Rhizobium (R)	72.05	74.62	4.41	5.27	39.11	43.16	4079.9	4503.1
		Mycorrhiza (M)	74.64	78.17	5.50	6.77	44.27	47.50	4618.9	4955.1
		R + M	77.42	80.91	6.08	7.94	57.05	63.16	5951.8	6589.5
LSD at 5 %			2.05	2.19	0.91	0.85	3.37	3.45	416.7	424.6

It is clear that the highest values of plant height, number of branches and leaves/plant, leaf area/plant, chlorophyll a, chlorophyll b, total chlorophyll and carotenoids contents in leaves, fresh and dry weights of shoot and root, number of nodules/plant, and fresh and dry weights of nodules in both seasons occurred without water stress treatment, i.e., irrigation level establish at 100% from water requirement (2818 m3/fed). The second-best irrigation treatment was intermediate water stress treatment *i.e.* irrigation levels at 80 % from water requirement (2254.4

m^3/fed) in both seasons. While, severe water stress treatment *i.e.* irrigation levels at 60 % from water requirement (1690.8 m^3/fed) produced the lowest values of plant height, number of branches and leaves/plant, leaf area/plant, chlorophyll a, chlorophyll b, total chlorophyll and carotenoids contents in leaves, fresh and dry weights of shoot and root, number of nodules/plant, fresh and dry weights of nodules in both seasons.

Increases in soybean growth characteristics brought about by irrigation at 100% of the water requirement (2818 m3/fed) may be attributed to the constant provision of moisture for soybean plants, which promotes improved growth and enhances vegetative growth characteristics. Conversely, water stress during the vegetative stage reduces photosynthesis and damages the plant's physiological and biochemical functions, which impacts plant development and productivity (Yavas *et al.*, 2024). These findings were in line with those published by Du *et al.* (2020), Dong *et al.* (2024), Petcu *et al.* (2024), and Yavas *et al.* (2024).

Effect of seed priming treatments:

It is clear from the statistical analysis of the data that was gathered about vegetative growth parameters *,i.e;* plant height, number of branches and leaves/plant, leaf area/plant, photosynthetic pigments, fresh and dry weights of shoots and roots, number of nodules/plant, fresh and dry weights of nodules, that there were significant effects on all of the growth parameters, yield and its constituents, and seed quality characteristics of soybean in both seasons (Tables 2, 4, 6, and 8).

It was observed that seed priming with calcium chloride ($CaCl_2$) at a rate of 6 g/L resulted in the highest values for plant height, number of branches and leaves per plant, leaf area per plant, photosynthetic pigments, in leaves, as well as the fresh and dry weights of both shoot and root, the number of nodules per plant, and the fresh and dry weights of nodules in both seasons. Seed priming with seaweed extract at a rate of 8 g/L ranked second, followed by seed priming with humic acid at 2 g/L, and then seed priming with distilled water (hydropriming) in both seasons. On the other hand, the control treatment (dry seed, no seed priming) showed the lowest values for all of these metrics in both seasons.

Increases in soybean growth characteristics linked to seed priming in calcium chloride (CaCl2), seaweed extract, humic acid, and hydropriming may indicate that calcium chloride is a stress-reduction technique, it increases the activity of antioxidant enzymes and decreases lipid peroxidation of cell membranes during abiotic stress (Hironari and Takashi, 2014). Aside from growth promoting compounds like IAA, kinetin, zeatin, gibberellins, auxins, and cytokinins, seaweeds are also a great source of metabolic enhancers including vitamins, amino acids, and macro and microelements. Faster seed germination and establishment, increased crop performance and yield, and higher resilience to biotic and abiotic challenges are only a few of the positive outcomes of their application in crop plants (Zhang and Ervin, 2004). Furthermore, chemical priming with humic compounds is showing promise as a technique for agricultural stress management and plant stress physiology (Canellas *et al*., 2020). These findings are consistent with those reported by Aminu *et al.* (2014) and Chavan et al., 2020). These results are in line with those published by Aminu *et al*. (2022), Oliveira *et al.* (2024), Rao *et al*. (2024), and Chavan *et al*. (2014).

Effect of biofertilization treatments:

The data obtained demonstrated that during the two growing seasons of 2022 and 2023, all of the studied growth parameters (plant height, number of branches and leaves/plant, leaf area/plant, photosynthetic pigments "chlorophyll a, chlorophyll b, total chlorophyll and carotenoids," fresh and dry weights of shoot and root, number of nodules/plant, and fresh and dry weights of nodules) were significantly impacted by the studied biofertilization treatments, namely, inoculation with *Rhizobium japonicum*, inoculation Mycorrhiza, and seed inoculation *Rhizobium japonicum* + Mycorrhiza (Tables 2, 4, 6, and 8).

Table 4. Chlorophyll a, chlorophyll b, total chlorophyll and carotenoids in soybean leaves as affected by irrigation levels, seed priming and biofertilization treatments as well as their interactions during 2022 and 2023 seasons.

Characters Treatments	**Chlorophyll a (mg/g FW)**		**Chlorophyll b (mg/g FW)**		**Total chlorophyll (mg/g FW)**		**Carotenoids (mg/g FW)**	
Seasons	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
A. Irrigation levels (as a ratio from water requirement):								
100 %	3.66	3.96	2.24	2.32	5.91	6.28	286.3	294.9
80 %	2.56	2.88	1.26	1.30	3.82	4.18	202.6	210.4
60 %	1.52	1.86	0.68	0.70	2.20	2.56	125.6	134.8
LSD at 5 %	0.03	0.02	0.03	0.03	0.03	0.02	1.5	1.2
B. Seed priming treatments:								
Without	2.00	2.29	0.84	0.90	2.84	3.18	153.4	162.1
Hydropriming	2.19	2.51	1.02	1.05	3.21	3.57	171.9	180.1
Calcium chloride	3.03	3.39	1.93	1.97	4.96	5.36	251.2	260.0
Humic acid	2.70	3.02	1.41	1.44	4.12	4.47	209.3	218.2
Seaweed extract	2.97	3.28	1.78	1.82	4.75	5.11	238.4	246.4
LSD at 5 %	0.03	0.02	0.04	0.04	0.04	0.03	1.7	1.6
C. Biofertilization treatments:								
Without	2.22	2.53	0.98	1.01	3.20	3.54	173.4	182.6
Rhizobium japonicum	2.52	2.81	1.33	1.38	3.85	4.19	198.6	206.6
Mycorrhiza	2.72	3.03	1.52	1.56	4.24	4.59	214.2	222.6
Rhizobium japonicum + Mycorrhiza	2.86	3.23	1.75	1.79	4.61	5.02	233.1	241.7
LSD at 5 %	0.03	0.02	0.03	0.03	0.03	0.02	1.3	1.1
D- Interactions (F. test):								
A × B	*	*	*	*	*	*	*	*
A × C	*	*	*	*	*	*	*	*
B × C	*	*	*	*	*	*	*	*
A × B × C	*	*	*	*	*	*	*	*

Table 5. Chlorophyll a, chlorophyll b, total chlorophyll and carotenoids in soybean leaves as affected by the interaction among irrigation levels, seed priming and biofertilization treatments during 2022 and 2023 seasons.

Treatments			Chlorophyll a (mg/g FW)		Chlorophyll b (mg/g FW)		Total chlorophyll (mg/g FW)		Carotenoids (mg/g FW)	
Irrigation levels	**Seed priming**	**Biofertilization**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
100 % of water require-ment	Without	Without	2.48	2.65	0.61	0.73	3.10	3.38	177.7	190.7
		Rhizobium (R)	3.07	3.19	1.15	1.28	4.22	4.47	213.8	221.6
		Mycorrhiza (M)	3.19	3.44	1.39	1.44	4.59	4.89	217.1	226.8
		R + M	3.36	3.66	1.57	1.66	4.93	5.32	235.9	246.8
	Hydrop-riming	Without	2.66	2.95	1.12	1.22	3.78	4.17	192.3	200.1
		Rhizobium (R)	3.23	3.40	1.46	1.61	4.69	5.01	229.3	235.6
		Mycorrhiza (M)	3.44	3.75	1.63	1.66	5.07	5.42	250.8	255.7
		R + M	3.51	3.73	1.73	1.84	5.24	5.58	257.1	266.8
	Calcium chloride	Without	3.70	4.13	2.14	2.05	5.84	6.19	292.5	303.4
		Rhizobium (R)	4.17	4.57	3.25	3.18	7.43	7.75	333.8	342.2
		Mycorrhiza (M)	4.21	4.57	3.72	3.81	7.93	8.41	390.4	397.7
		R + M	4.29	4.69	4.11	4.30	8.40	9.00	434.1	439.3
	Humic acid	Without	3.43	3.73	1.73	1.82	5.16	5.55	255.2	266.1
		Rhizobium (R)	3.68	4.03	2.05	1.99	5.73	6.02	270.1	281.1
		Mycorrhiza (M)	4.34	4.56	2.06	2.46	6.41	7.02	299.6	305.5
		R + M	4.17	4.59	3.05	3.03	7.23	7.62	326.8	334.3
	Seaweed extract	Without	3.68	4.00	1.73	1.76	5.41	5.77	266.9	274.6
		Rhizobium (R)	4.20	4.44	2.90	2.93	7.10	7.37	325.3	331.6
		Mycorrhiza (M)	4.20	4.51	3.46	3.44	7.66	7.95	361.5	372.1
		R + M	4.27	4.59	3.94	4.12	8.22	8.69	396.5	405.9
80 % of water require-ment	Without	Without	1.78	1.89	0.65	0.80	2.44	2.69	130.5	139.4
		Rhizobium (R)	1.85	2.23	0.92	0.91	2.78	3.14	162.0	166.8
		Mycorrhiza (M)	2.02	2.29	0.84	0.98	2.86	3.28	170.2	177.8
		R + M	2.28	2.48	1.00	1.17	3.28	3.65	183.2	191.1
	Hydrop-riming	Without	1.79	2.19	0.79	0.80	2.59	2.99	152.4	159.3
		Rhizobium (R)	2.16	2.49	1.02	1.08	3.19	3.57	183.0	188.8
		Mycorrhiza (M)	2.25	2.57	1.15	1.14	3.40	3.72	188.5	199.4
		R + M	2.46	2.81	1.09	1.08	3.55	3.89	197.7	205.9
	Calcium chloride	Without	2.62	2.84	1.20	1.31	3.82	4.16	207.6	217.8
		Rhizobium (R)	2.78	3.15	1.45	1.42	4.23	4.58	225.0	236.5
		Mycorrhiza (M)	3.31	3.62	1.70	1.64	5.01	5.27	232.1	238.2
		R + M	3.59	4.05	2.17	2.34	5.76	6.40	268.4	277.2
	Humic acid	Without	2.43	2.79	1.06	1.08	3.49	3.88	194.6	204.9
		Rhizobium (R)	2.55	2.77	1.22	1.34	3.77	4.12	207.0	213.6
		Mycorrhiza (M)	2.63	2.93	1.36	1.27	3.99	4.20	211.6	219.7
		R + M	2.73	3.15	1.45	1.39	4.19	4.54	225.1	231.7
	Seaweed extract	Without	2.49	2.79	1.24	1.21	3.73	4.00	203.9	209.7
		Rhizobium (R)	2.72	2.96	1.35	1.42	4.07	4.38	222.0	229.3
		Mycorrhiza (M)	3.12	3.46	1.75	1.70	4.87	5.16	228.3	236.2
		R + M	3.56	4.04	1.84	1.84	5.41	5.89	258.2	265.8
60 % of water require-ment	Without	Without	0.82	1.35	0.12	0.02	0.94	1.23	74.5	81.6
		Rhizobium (R)	0.83	1.18	0.55	0.65	1.39	1.83	85.2	92.4
		Mycorrhiza (M)	1.18	1.57	0.53	0.45	1.71	2.03	84.9	95.4
		R + M	1.18	1.59	0.70	0.68	1.89	2.28	105.6	114.5
	Hydrop-riming	Without	0.87	1.31	0.22	0.16	1.09	1.47	76.4	88.7
		Rhizobium (R)	1.20	1.61	0.59	0.60	1.79	2.22	100.6	107.1
		Mycorrhiza (M)	1.25	1.59	0.72	0.71	1.97	2.30	113.8	121.7
		R + M	1.44	1.73	0.73	0.73	2.18	2.47	120.7	132.2
	Calcium chloride	Without	1.69	1.92	0.66	0.78	2.35	2.71	130.3	138.5
		Rhizobium (R)	1.83	2.21	0.74	0.74	2.57	2.96	155.9	166.9
		Mycorrhiza (M)	2.05	2.31	0.86	0.98	2.91	3.30	168.7	177.7
		R + M	2.17	2.62	1.14	1.04	3.31	3.67	175.6	185.3
	Humic acid	Without	1.28	1.63	0.79	0.69	2.07	2.33	118.4	127.4
		Rhizobium (R)	1.63	1.91	0.68	0.75	2.32	2.66	127.7	138.4
		Mycorrhiza (M)	1.76	1.97	0.70	0.76	2.47	2.73	136.5	146.1
		R + M	1.81	2.17	0.74	0.75	2.56	2.92	139.2	149.7
	Seaweed extract	Without	1.53	1.84	0.70	0.79	2.24	2.63	127.4	137.3
		Rhizobium (R)	1.84	2.03	0.64	0.77	2.48	2.81	138.8	147.1
		Mycorrhiza (M)	1.91	2.22	0.86	0.98	2.78	3.21	159.4	168.6
		R + M	2.10	2.49	0.95	0.92	3.06	3.42	173.1	179.2
LSD at 5 %			0.10	0.07	0.14	0.013	0.12	0.10	4.5	4.2

Compared to other biofertilization treatments, seed inoculation with *Rhizobium japonicum* in addition to Mycorrhiza produced the highest values of plant height, number of branches and leaves/plant, leaf area/plant, chlorophyll a, chlorophyll b, total chlorophyll and carotenoids contents in leaves, fresh and dry weights of shoot and root, number of nodules/plants, and fresh and dry weights of nodules. In both seasons, mycorrhiza inoculation follows. *Rhizobium japonicum* is used to inoculate the seeds. In contrast, The lowest values of plant height, number of branches and leaves/plant, leaf area/plant, chlorophyll a, chlorophyll b, total chlorophyll and carotenoids contents in leaves, fresh and dry weights of shoot and root, number of nodules/plant, and fresh and dry weights of nodules were obtained in the control treatment (without inoculation with biofertilizers) in both seasons.

Table 6. Fresh and dry weights of shoot and root of soybean plants as affected by irrigation levels, seed priming and biofertilization treatments as well as their interactions during 2022 and 2023 seasons.

Characters Treatments	Fresh weight of shoot (g)		Dry weight of shoot (g)		Fresh weight of root (g)		Dry weight of root (g)	
Seasons	2022	2023	2022	2023	2022	2023	2022	2023
A. Irrigation levels (as a ratio from water requirement):								
100 %	215.6	225.9	60.14	63.81	15.44	16.26	6.41	6.90
80 %	117.4	127.3	39.21	42.47	7.80	8.55	3.62	4.10
60 %	65.6	74.5	23.34	26.67	4.65	5.48	2.00	2.48
LSD at 5 %	0.6	0.8	0.30	0.27	0.15	0.20	0.04	0.05
B. Seed priming treatments:								
Without	76.1	84.0	26.19	29.49	5.40	6.21	2.02	2.48
Hydropriming	96.0	105.1	31.82	35.18	6.88	7.60	2.61	3.10
Calcium chloride	183.4	192.4	52.23	55.71	12.59	13.56	5.80	6.35
Humic acid	141.7	152.1	44.36	48.63	9.84	10.64	4.25	4.72
Seaweed extract	167.2	179.3	49.86	52.58	11.78	12.46	5.37	5.83
LSD at 5 %	0.8	1.0	0.39	0.34	0.20	0.25	0.06	0.07
C. Biofertilization treatments:								
Without	101.3	110.2	33.85	37.22	6.94	7.65	2.87	3.26
Rhizobium japonicum	127.1	137.3	39.89	42.81	8.70	9.51	3.79	4.27
Mycorrhiza	144.2	154.0	43.04	46.73	10.06	10.91	4.34	4.86
Rhizobium japonicum + Mycorrhiza	158.9	168.7	46.79	50.50	11.50	12.30	5.04	5.58
LSD at 5 %	0.8	1.0	0.34	0.34	0.17	0.20	0.04	0.06
D- Interactions (F. test):								
A × B	*	*	*	*	*	*	*	*
A × C	*	*	*	*	*	*	*	*
B × C	*	*	*	*	*	*	*	*
A × B × C	*	*	*	*	*	*	*	*

These improvements in soybean growth characteristics brought about by Mycorrhiza inoculation or Rhizobium japonicum seed inoculation may be explained by the fact that Mycorrhiza increased the activity of fungal succinate dehydrogenase stained in the root tissues, which in turn stimulated plant growth and nutrient contents of soybean (Al-Amri, 2019). Additionally, by controlling hormonal and nutritional balance, generating plant growth regulator, solubilizing minerals, and including resistance against plant diseases, *Rhizobium japonicum* can stimulate plant development (Nadeem *et al*., 2014). Wen et al. (2023), Islam *et al*. (2021), Rabiul *et al*. (2020), and Subaedah *et al*. (2024) all found similar findings.

Effect of interactions:

Significant effects were observed in both seasons on growth parameters (plant height, amount of branches and leaves/plant, leaf area/plant, photosynthetic pigments, fresh and dry weights of shoot and root, number of nodules/plants, and fresh and dry weights of nodules) as a result of the various interactions among the three factors under study, namely irrigation levels, seed priming, and biofertilization treatments.

The growth parameters of soybeans in both seasons were significantly impacted by the relationships between irrigation levels, seed priming, and biofertilization treatments. The highest values of plant height, number of branches and leaves/plant, leaf area/plant, chlorophyll a, chlorophyll b, total chlorophyll and carotenoids contents in leaves, fresh and dry weights of shoot and root, number of nodules/plant, and fresh and dry weights of nodules were obtained by irrigation soybean plants at 100% water requirement (2818 m3/fed) and priming seeds in calcium chloride ($CaCl_2$) at a rate of 6 g/L. In addition, seeds were inoculated with *Rhizobium japonicum* and Mycorrhiza in both seasons (Tables 3, 5, 7, and 9).

The second-best interaction treatment was irrigating soybean plants at 100% of their water requirement (2818 m^3/fed) while priming seeds with seaweed extract at a rate of 8 g/L, along with inoculating the seeds with *Rhizobium japonicum* and Mycorrhiza. This was followed by irrigating soybean plants at the same 100% water requirement level and priming seeds with calcium chloride ($CaCl_2$) at 6 g/L, combined with *Mycorrhiza* inoculation, in both seasons. To optimize water, use while maintaining high growth parameters in soybean, it is recommended to irrigate soybean plants at 80% of their water requirement and prime seeds with $CaCl_2$ at 6 g/L, in addition to inoculating the seeds with *Rhizobium japonicum* and Mycorrhiza. This treatment significantly outperformed the control treatment, which is commonly practiced by soybean farmers (irrigating plants at 100% of their water requirement without seed priming or biofertilizer inoculation). On the other hand, irrigating soybean plants at 60% of their water requirement (1690.8 m^3/fed) without seed priming or biofertilizer inoculation resulted in the lowest values for plant height, amount of branches and leaves per plant, leaf area per plant, chlorophyll a, chlorophyll b, total chlorophyll, carotenoid content in leaves, fresh and dry weights of shoot and root, number of nodules per plant, and fresh and dry weights of nodules for both seasons.

Table 7. Fresh and dry weights of shoot and root of soybean plants as affected by the interaction among irrigation levels, seed priming and biofertilization treatments during 2022 and 2023 seasons.

Treatments			Fresh weight of shoot (g)		Dry weight of shoot (g)		Fresh weight of root (g)		Dry weight of root (g)	
Irrigation levels	Seed priming	Biofertilization	2022	2023	2022	2023	2022	2023	2022	2023
100 % of water require-ment	Without	Without	99.3	104.4	32.56	35.23	6.25	6.71	2.67	3.27
		Rhizobium (R)	110.3	117.7	38.75	41.89	9.69	10.41	3.36	3.90
		Mycorrhiza (M)	119.6	130.4	42.53	47.26	10.75	11.72	3.55	4.30
		R + M	159.3	167.3	45.37	49.37	12.64	14.16	4.85	5.28
	Hydrop-riming	Without	107.9	117.1	34.37	38.52	8.33	8.67	2.90	3.35
		Rhizobium (R)	148.5	159.1	44.22	46.59	11.09	12.13	4.69	5.14
		Mycorrhiza (M)	182.0	190.5	53.13	57.51	13.24	14.56	4.87	5.42
		R + M	193.2	204.8	60.02	63.57	13.92	14.53	5.20	5.67
	Calcium chloride	Without	236.8	244.0	65.71	70.28	15.68	16.69	6.57	6.83
		Rhizobium (R)	301.2	311.3	74.61	76.59	18.92	20.30	8.71	9.41
		Mycorrhiza (M)	315.6	324.3	76.96	81.13	22.36	23.17	9.67	10.12
		R + M	328.8	340.5	83.71	88.26	25.10	25.62	11.23	11.97
	Humic acid	Without	178.5	190.6	57.07	61.14	13.67	14.75	5.12	5.54
		Rhizobium (R)	235.0	246.5	63.47	67.32	15.61	16.31	6.36	6.78
		Mycorrhiza (M)	247.6	257.1	68.69	72.10	16.18	16.82	7.08	7.44
		R + M	267.5	279.0	73.47	77.32	18.24	19.33	8.13	8.53
	Seaweed extract	Without	198.6	211.9	63.20	66.83	15.17	15.27	6.28	6.68
		Rhizobium (R)	251.3	263.6	70.60	73.59	18.08	18.99	8.02	8.31
		Mycorrhiza (M)	308.4	320.9	76.16	79.31	20.85	21.68	9.12	9.57
		R + M	323.0	336.5	78.22	82.52	23.13	23.36	9.88	10.56
80 % of water require-ment	Without	Without	53.1	61.1	16.73	20.39	2.39	2.86	0.98	1.38
		Rhizobium (R)	63.5	71.8	25.51	27.95	3.72	4.69	1.53	2.07
		Mycorrhiza (M)	74.8	85.3	26.36	28.45	5.10	6.12	1.96	2.50
		R + M	87.8	97.0	30.24	33.72	7.17	7.76	2.46	2.95
	Hydrop-riming	Without	61.6	73.3	23.38	26.50	3.10	3.92	1.13	1.70
		Rhizobium (R)	76.6	88.1	29.81	31.30	5.61	6.55	2.14	2.72
		Mycorrhiza (M)	96.3	106.7	30.77	34.27	7.23	7.90	2.64	3.04
		R + M	108.0	115.4	36.85	41.53	7.48	8.19	3.02	3.71
	Calcium chloride	Without	129.5	139.4	46.15	50.14	8.10	9.08	4.03	4.44
		Rhizobium (R)	156.4	165.4	49.45	52.32	9.38	9.55	4.91	5.47
		Mycorrhiza (M)	170.6	180.1	51.61	55.21	10.73	11.80	5.87	6.52
		R + M	189.0	192.6	54.23	57.76	13.84	14.93	6.43	6.68
	Humic acid	Without	100.7	111.8	32.25	36.15	7.27	8.10	2.73	3.19
		Rhizobium (R)	122.2	131.0	42.12	45.40	7.88	8.94	3.84	4.08
		Mycorrhiza (M)	129.3	140.0	46.64	51.00	8.57	9.20	4.24	4.87
		R + M	144.2	155.3	48.67	52.38	9.27	9.47	4.75	5.46
	Seaweed extract	Without	116.0	126.4	41.57	45.75	7.63	8.39	3.84	3.96
		Rhizobium (R)	132.7	145.0	48.55	49.74	9.12	9.34	4.50	4.92
		Mycorrhiza (M)	158.3	170.4	51.09	55.43	10.65	11.41	5.11	5.81
		R + M	178.4	189.6	52.16	54.12	11.80	12.78	6.25	6.64
60 % of water require-ment	Without	Without	24.7	27.3	11.34	14.21	0.79	1.22	0.39	0.42
		Rhizobium (R)	35.0	46.2	13.31	17.43	0.90	2.00	0.58	0.96
		Mycorrhiza (M)	39.4	45.0	14.48	18.04	2.06	2.50	0.68	0.98
		R + M	46.3	54.4	17.15	19.95	3.35	4.39	1.30	1.79
	Hydrop-riming	Without	27.9	31.0	13.23	15.56	0.88	1.47	0.52	0.81
		Rhizobium (R)	42.0	50.1	15.41	18.46	2.74	3.19	1.04	1.58
		Mycorrhiza (M)	50.3	58.9	18.45	22.13	4.10	4.98	1.53	2.00
		R + M	58.3	66.4	22.26	26.27	4.87	5.10	1.71	2.13
	Calcium chloride	Without	69.6	78.1	25.73	28.64	5.52	6.55	2.39	2.70
		Rhizobium (R)	89.4	95.8	29.99	33.48	6.25	7.14	2.53	3.28
		Mycorrhiza (M)	103.5	114.5	32.24	35.07	6.95	8.12	3.22	4.10
		R + M	111.0	122.5	36.39	39.68	8.24	9.81	4.03	4.64
	Humic acid	Without	55.5	63.6	20.23	22.71	4.15	5.00	1.54	2.09
		Rhizobium (R)	66.9	78.8	24.87	28.11	5.49	6.45	2.24	2.66
		Mycorrhiza (M)	72.2	83.0	26.44	30.28	5.65	6.45	2.42	2.81
		R + M	80.8	88.0	28.46	39.68	6.15	6.93	2.52	3.14
	Seaweed extract	Without	60.6	72.7	24.29	26.33	5.18	6.17	2.05	2.62
		Rhizobium (R)	75.6	89.5	27.71	32.06	5.97	6.73	2.43	2.83
		Mycorrhiza (M)	95.0	103.8	30.05	33.85	6.43	7.17	3.15	3.49
		R + M	108.4	121.0	34.72	31.44	7.34	8.22	3.82	4.55
LSD at 5 %			1.9	2.0	1.35	1.34	0.68	0.75	0.17	0.20

Table 8. Number of nodules per plant, fresh and dry weights of nodules per soybean plants as affected by irrigation levels, seed priming and biofertilization treatments as well as their interactions during 2022 and 2023 seasons.

Characters Treatments	Number of nodules/plant		Fresh weight of nodules/plant (g)		Dry weight of nodules/plant (g)	
Seasons	2022	2023	2022	2023	2022	2023
A. Irrigation levels (as a ratio from water requirement):						
100 %	39.77	41.65	0.865	0.897	0.546	0.391
80 %	23.33	25.06	0.185	0.583	0.367	0.201
60 %	10.77	12.68	0.330	0.367	0.082	0.097
LSD at 5 %	0.31	0.32	0.012	0.015	0.009	0.007
B. Seed priming treatments:						
Without	13.65	15.32	0.139	0.222	0.089	0.045
Hydropriming	21.16	23.00	0.300	0.417	0.195	0.134
Calcium chloride	33.87	36.00	0.739	0.964	0.543	0.382
Humic acid	25.28	27.00	0.508	0.675	0.379	0.264
Seaweed extract	29.16	31.01	0.614	0.800	0.452	0.324
LSD at 5 %	0.40	0.42	0.015	0.018	0.010	0.009
C. Biofertilization treatments:						
Without	0.00	0.00	0.000	0.000	0.000	0.000
Rhizobium japonicum	43.93	47.40	0.771	1.056	0.550	0.381
Mycorrhiza	0.00	0.00	0.000	0.000	0.000	0.000
Rhizobium japonicum + Mycorrhiza	54.58	58.47	1.069	1.407	0.777	0.538
LSD at 5 %	0.43	0.40	0.013	0.011	0.008	0.006
D- Interactions (F. test):						
A × B	*	*	*	*	*	*
A × C	*	*	*	*	*	*
B × C	*	*	*	*	*	*
A × B × C	*	*	*	*	*	*

Table 9. Number of nodules per plant, fresh and dry weights of nodules per soybean plants as affected by the interaction among irrigation levels, seed priming and biofertilization treatments during 2022 and 2023 seasons.

Treatments			Number of nodules/plant		Fresh weight of nodules/plant (g)		Dry weight of nodules/plant (g)	
Irrigation levels	**Seed priming**	**Biofertilization**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
100 % of water require-ment	Without	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	32.31	35.55	0.467	0.533	0.080	0.120
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	54.34	56.83	0.633	0.700	0.100	0.150
	Hydrop-riming	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	74.23	78.55	1.100	1.200	0.330	0.373
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	76.07	79.11	1.300	1.333	0.513	0.553
	Calcium chloride	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	89.66	93.16	2.467	2.533	1.040	1.083
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	116.73	123.16	3.100	3.100	1.433	1.473
	Humic acid	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	80.70	83.50	1.433	1.533	0.723	0.787
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	83.68	87.50	2.300	2.367	0.983	1.000
	Seaweed extract	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	81.78	85.16	1.833	1.933	0.777	0.853
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	105.96	110.50	2.667	2.700	1.363	1.417
80 % of water require-ment	Without	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	24.48	27.50	0.067	0.467	0.380	0.073
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	29.87	32.94	0.100	0.500	0.453	0.100
	Hydrop-riming	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	30.83	34.94	0.100	0.633	0.553	0.157
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	41.07	44.44	0.300	0.867	0.797	0.330
	Calcium chloride	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	57.99	61.50	0.533	1.600	1.493	0.603
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	79.66	83.16	0.700	2.067	1.947	0.747
	Humic acid	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	41.46	44.50	0.400	1.067	1.013	0.400
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	51.98	55.50	0.467	1.533	1.440	0.507
	Seaweed extract	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	46.14	49.72	0.400	1.267	1.200	0.440
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	63.28	67.11	0.633	1.667	1.650	0.667
60 % of water require-ment	Without	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	10.43	14.55	0.167	0.200	0.020	0.037
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	12.40	16.50	0.233	0.267	0.033	0.057
	Hydrop-riming	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	15.35	19.50	0.300	0.400	0.043	0.073
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	16.45	19.50	0.500	0.567	0.107	0.120
	Calcium chloride	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	29.93	32.83	0.867	0.967	0.257	0.293
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	32.55	38.16	1.200	1.300	0.350	0.387
	Humic acid	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	21.21	24.50	0.700	0.733	0.160	0.200
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	24.32	28.50	0.800	0.867	0.230	0.270
	Seaweed extract	Without	0.00	0.00	0.000	0.000	0.000	0.000
		Rhizobium (R)	22.49	25.51	0.733	0.767	0.180	0.220
		Mycorrhiza (M)	0.00	0.00	0.000	0.000	0.000	0.000
		R + M	30.33	34.16	1.100	1.267	0.257	0.293
LSD at 5 %			1.60	1.52	0.050	0.060	0.030	0.025

CONCLUSION

It can be concluded from the study's results that irrigation soybean plants irrigation at the level of 100 % from water requirement (2818 m^3/fed) and priming seeds in calcium chloride ($CaCl_2$) at rate 6 g/L in addition inoculation seeds with *Rhizobium japonicum* as well inoculation with Mycorrhiza to obtain maximum growth parameters.

While, in order to save irrigation water at the same time maintaining highest growth parameters, it could be recommended that irrigation soybean plants at the level of 80 % from water requirement (2254.4 m^3/fed) and priming seed in $CaCl_2$ at rate 6 g/L besides inoculation seeds with *Rhizobium japonicum* in addition inoculation with Mycorrhiza inside the environmental circumstances of Egypt's Dakahlia Governorate's Mansoura district.

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تأثير معاملات تهيئة البذور والتسميد الحيوي على صفات النمو الخضري لفول الصويا تحت ظروف الإجهاد المائي

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[2] قسم المحاصيل، كلية الزراعة، جامعة دمياط، مصر.

الملخص

أجريت هذه الدراسة في المزرعة التجريبية بكلية الزراعة، جامعة المنصورة، محافظة الدقهلية، مصر، خلال موسمي 2022 و2023 لتحسين نمو فول الصويا باستخدام معاملات تهيئة البذور والتسميد الحيوي تحت ظروف الإجهاد المائي (مستويات الري كنسبة مئوية من المقنن المائى"2818 م ^{3} / فدان "). تم تنفيذ كل مستوى ري في تجربة مستقلة ثم تم تنفيذ كل تجربة لمستويات الري فى تصميم الشرائح المتعامدة في ثلاث مكررات. وقد خصصت القطع الرأسية لمعاملات تهيئة البذور فى حين تم تخصيص القطع الأفقية لمعاملات التسميد الحيوي. من النتائج المتحصل عليها يتضح أنه بدون إجهاد مائي أي الري عند مستوى 100٪ من المقنن المائى (2818 م ^{3} / فدان) أدى إلى الحصول على أعلى القيم لصفات النمو الخضرى في كلا الموسمين. وقد لوحظ أن معاملة تهيئة البذور بكلوريد الكالسيوم بمعدل 6 جرام/لتر أعطت أعلى القيم لصفات النمو الخضرى في كلا الموسمين. تفوقت معاملة تلقيح البذور بـ *Rhizobium japonicum* + الميكورهيزا على معاملات التسميد الحيوي الأخرى وأعطت أعلى القيم لصفات النمو الخضرى في كلا الموسمين. ومن أجل توفير مياه الري مع الحفاظ على أعلى نمو ومحصول ومكوناته وصفات جودة للبذور، يمكن التوصية بري نباتات فول الصويا عند مستوى 80% من المقنن المائى و تهيئة البذور بكلوريد الكالسيوم بمعدل 6 جم/لتر إلى جانب تلقيح البذور بـ *Rhizobium japonicum* بالإضافة إلى التلقيح بالميكورهيزا تحت الظروف البيئية لمنطقة المنصورة، محافظة الدقهلية، مصر.