

Effect of Using Plant Residues, Bio-fertilizers and Irrigation Intervals in the Growth and Yield of Beet Plants to Enhance Sustainability

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Abstract

The experiment was conducted at the desert demonstration farm in the holy city of Karbala, affiliated to the Extension Center during 2024-2025 agricultural season to study the role of plant residues and bio-fertilizers in improving the growth and productivity of beet plant under the influence of irrigation intervals to Enhancing Sustainable Development. Three factors were used, the first factor involved three irrigation intervals (A1 irrigation based on plant and soil's field capacity requirements, A2 irrigation three days after plant and soil's field capacity requirements and A3 irrigation six days after plant and soil's field capacity requirements), the second factor involved three levels of fertilization with plant residues (B1 control treatment [addition NPK + Urea fertilizer], B2 addition of partially decomposed palm frond residues with 25% NPK + Urea and B3 addition of partially decomposed rice residues with 25% NPK + Urea) according to the recommended fertilizer application, the third factor involved three levels of bio-fertilizers (C1 control treatment without addition, C2 addition of Trichoderma fungus and C3 addition of mycorrhizal fungus). The experiment was designed as a factorial split-split-plot experiment and it was conducted in three replicates, each consisting of 27 experimental units in each experimental unit 20 beet plant seeds of the Detroit variety were planted using a drip irrigation system, the seeds were sown in the field from October 15, 2024, until the final harvest on February 15, 2025. The results showed that irrigation treatment A1 recorded the highest values for the number of leaves, leaf chlorophyll content, shoot dry weight, root weight, root carbohydrate and alpha-lipoic acid content (19.35 leaf plant⁻¹, 112.9 mg/100g, 25.38 g, 316.1 g, 1.850 micrograms g⁻¹, and 356.8 micrograms/ml) respectively with a significant difference compared to treatments A2 and A3. Except the dry weight of roots treatment A1 did not differ significantly from treatment A2 which amounted to (22.58g). Treatment B1 recorded the highest values for shoot dry weight and root alpha-lipoic acid content (23.22 g and 324.9 micrograms/ml) respectively and treatment B2 for root carbohydrate content (1.608 micrograms g⁻¹) and treatment B3 for number of leaves, leaf chlorophyll content, and root weight (17.65 leaf plant⁻¹, 98.5 mg/100 g, and 289.5 g,) respectively with no significant difference compared with most of the other treatments. Treatment C3 showed the highest value for the number of leaves and root content of alpha-lipoic acid (18.23 leaf plant⁻¹, 323.3 micrograms/ml) respectively, and treatment C2 for the leaf content of chlorophyll, shoot dry weight, root weight, and root carbohydrate content (100.4 mg/100g, 22.76g, 295.5g, 1.606 micrograms g⁻¹) respectively with a significant difference from treatment C1 except for the root carbohydrate content.

Key words: Sustainability, Irrigation scheduling, Plant residues, Bio-fertilizers

Introduction

Focusing on the quality of agricultural crop production is a crucial objective today, it is a fundamental pillar of healthy nutrition and environmentally safe production which directly impacts individual health, this is achieved through using of modern and sustainable agricultural practices that keep pace with scientific advancements, hence the importance of the beetroot plant, *Beta vulgaris* L. belonging to the Chenopodiaceous family, it is a winter root vegetable crop although the edible part is the enlarged lower embryonic stalk (hypocotyl) in addition to the upper part of the taproot [40]. It is our storehouse for many nutrients such as iron, potassium, sulfur, silicon, phosphorus, zinc, magnesium, manganese and nitrates as well as a group of vitamins (A, B1, B2, B6, C), and it also contains amino acids, organic acids, folic acid, carbohydrates, betalain pigment and cellulose furthermore it contains antioxidants such as alpha-lipoic acid [37] [49], Therefore, the importance of studying beet plant crops has increased as they require the production of roots with regular and balanced growth between the shoot and root systems, this necessitates providing a suitable growing environment that supplies the plant with essential nutrients and ensures adequate moisture in the root zone [47].

One of the most important environmental factors in plant growth is the lack of irrigation water which leads to a reduction in production in terms of both quantity and quality, the spacing of irrigation intervals reduces the photosynthesis process and increases leaf deterioration with a decrease in the efficiency of nutrient absorption, slow cell growth and elongation and a decrease in leaf expansion causing the stomata to close and limiting crop growth [12] [52] [57]. The increasing population and their industrial activity coupled with the drought that the desert region of Iraq suffers from as a result of the lack of rain and irrigation water, hot climatic conditions, and the excessive use of chemical fertilizers and

pesticides, made it necessary to depend on the development of sustainable agriculture, the use of local natural resources, their recycling, and the introduction of some organic farming methods to reduce the negative effects of chemicals, reduce the costs of purchasing chemical fertilizers and pesticides, increase environmental diversity, obtain safe food for humans free from pollutants and harmful chemicals as well as the optimal use of natural resources such as irrigation water, reducing its loss and maintaining moisture in the root zone as much as possible [29]. It is necessary to use alternatives to chemical fertilizers such as plant residues like palm fronds and rice residues, which can be used as organic fertilizer where it is added after being recycled and partially decomposed so that the plant can benefit from it, it is characterized by its local availability and low cost, and it can be relied upon to reduce chemical fertilizers that are harmful to the environment [46]. Organic matter is considered one of the basic components of the soil which is effect indirect on plant growth, it improves the physical, chemical, and biological properties of the soil by regulating soil pH and reducing its salinity, especially when irrigating with saline water in desert areas that use well water to irrigate agricultural crops, it also plays a major role in activating beneficial microbial colonies and increasing their populations, thus providing a suitable environment for plant [36] [38].

One of the modern methods in developing sustainable agriculture to improve the quality characteristics of the crop and increase plant growth and productivity is the use of bio-fertilizers, which contain beneficial microorganisms added to the soil, it is increase the supply of the plant with some of its needs for nutrients[15] [18], it also secrete growth-stimulating substances such as hormone-like substances and protect the plant from biological stresses (pathogens in the soil) and increase its tolerance to environmental stress conditions (salinity and drought), it also

secrete sticky compounds that improve soil structure and aggregate its particles, it is a relationship between the functions of microorganisms in the soil and the organic components of the soil [21] [43]. Trichoderma and mycorrhizae are considered beneficial fungi that are used as bio-fertilizers, many experiments have shown the ability of Trichoderma and mycorrhizae to absorb nutrients in the soil and increase the concentration within plant tissues such as nitrogen, phosphorus, potassium, manganese, copper, iron, and zinc [2] [10]. Therefore, the study is distinguished by using factors (irrigation intervals, fertilization with plant residues, fertilization with bio-fertilizers) to evaluate the efficiency of plant residues (palm fronds and rice residues) and bio-fertilizers (Trichoderma and Mycorrhizae) and the extent of their effect on the plant's tolerance to biological and environmental stresses, increasing growth and yield, and the possibility of achieving optimal use of natural resources that are compatible with the requirements of sustainability and agricultural development .

Materials and Methods

The experiment was conducted during the 2024-2025 growing season in the fields of the Desert Demonstration Farm – Ministry of Agriculture – Department of Agricultural Extension and Training – Agricultural Extension and Training Center in the Holy City of Karbala, to study the role of plant residues and bio-fertilizers in improving the growth and productivity of beet plant under the influence of irrigation intervals to Enhancing Sustainable Development, the crop was planted in open fields in lines with a spacing 25 cm between lines and 20 cm between plants, there were four lines in each experimental unit with 20 plants per unit, the area of each experimental unit was 1 m², and the distance between experimental units was 1

m within a single replicate, with a distance of 2 m between replicates.

Experiment design

The experiment was designed as a factorial split- split-plot experiment, irrigation intervals treatments were distributed in the main plots, plant residues treatments in the sub-plots, and bio-fertilizers treatments in the sub-sub-plots with three replicates using a randomized complete block design (RCBD),(

therefore, the number of experimental units (3×3×3) was 27 per replicate, totaling 81 experimental units across the three replicates, means were compared using the least significant difference (LSD) method at a probability level of 0.05 [11.]

Study factors

The first factor: Irrigation intervals, denoted by (A): A1 Comparison treatment: Irrigation according to the plant and soil's needs from the field capacity + A2 Irrigation 3 days after the plant and soil's needs from the field capacity + A3 Irrigation 6 days after the plant and soil's needs from the field capacity.

The soil field capacity was estimated on a dry weight basis and a field capacity of 50% was adopted as the minimum for irrigating the beet plant [13.]

Irrigation intervals were applied to the treatments 3 weeks after germination, after the growth of true leaves and the plant beginning to manufacture food on its own.

Field capacity = $\frac{\text{Wet weight of soil} - \text{Dry weight of soil}}{\text{Dry weight of soil}} \times 100$

The second factor: Plant residues, were prepared by the organic fertilizer project in Najaf, denoted by (B): B1 Comparison

treatment: Addition of chemical fertilizer NPK and Urea according to the approved recommendation [31] + B2 Addition of palm

frond residues 40 tons h-1 with (25% NPK and Urea) + B3 Addition of rice residues 40 tons h-1 with (25% NPK and Urea.)

Table 2 shows the chemical and physical properties of plant residues.

Analysis	Palm frond Residues	Rice Residues
PH	7.04	6.50
Electrical Conductivity dc.cm	2.66	0.93
C %	43.70	44.6
C/N %	19.00	18.0
N %	2.30	2.48
P %	0.650	0.540
K %	2.80	0.260

The third factor: Bio-fertilizers, were prepared by the Department of Agricultural Research at the Biotechnology Center of the Ministry of Science and Technology, denoted by (C): C1 Control treatment (without addition) + C2 Addition of Trichoderma fungus Carried on peat moss isolate T6 asperellum fungus with an inoculant density of 7×10^{11} cfu/mL (10) g per hole during seed planting + C3 Addition of Mycorrhizae fungus Carried on peat moss with an inoculant density of 50 spores per gram of soil - 1 (10) g per hole during seed planting [28].

Studied characteristics

-1Number of leaves leaf plant-1.

-2Chlorophyll content in leaves (mg/100g) fresh weight: Estimated according to the method of [24].

-3Dry weight of shoot (g.)

-4Root weight (g.)

-5Carbohydrate content of roots (micrograms g-1) dry matter: Estimated according to the method of [33].

-6Alpha-lipoic acid estimation in root (microgram /ml): Estimated according to the method of [39].

Results

Table 3 shows that the individual effect of irrigation intervals treatments showed a significant decrease as the irrigation treatment A1 recorded the highest values for all studied traits, while irrigation treatment A3 recorded the lowest, regarding the individual effect of plant residues treatment B1 achieved the highest value compared to the other plant residue treatments B2 and B3, Meanwhile, the individual effect of bio-fertilizers in treatments C2 and C3 recorded the highest values for all studied traits with significantly different from treatment C1 for most of the studied traits.

Regarding the effect of the dual interaction between irrigation intervals and plant residues, treatment

A1B1 recorded the highest values for the traits compared to the other interaction treatments, while treatment A3B1 recorded the lowest values for most of the studied traits, as for the effect of the dual interaction between studied traits, furthermore, the dual interactions between plant residue and bio-

irrigation intervals and bio-fertilizers, treatments A1C2 and A1C3 recorded the highest values for all traits compared with treatment A3C1, which recorded the lowest values for all

Table 3 shows the individual and dual effects of irrigation intervals, plant residues, and bio-fertilizers in improving the growth and productivity of beet plant.

Treatment	Number of leaves leaf plant ⁻¹ .	Chlorophyll content in leaves (mg/100g)	Dry weight of shoot (g)	Root weight (g).	Carbohydrate content of roots (micrograms g ⁻¹)	Alpha-lipoic acid estimation in root (microgram /ml)
A1	19.35	112.9	25.38	316.1	1.850	356.8
A2	17.71	96.3	22.58	288.8	1.588	329.6
A3	14.28	79.0	17.12	259.5	1.292	261.2
LSD A	1.110	6.74	3.659	7.71	0.1441	23.15
B1	16.92	94.5	23.22	288.9	1.566	324.9
B2	16.77	95.2	21.11	285.9	1.608	307.2
B3	17.65	98.5	20.75	289.5	1.557	315.5
LSD B	0.997	3.92	2.201	7.66	0.1772	23.07
C1	15.45	90.2	19.58	278.0	1.520	302.6
C2	17.66	100.4	22.76	295.5	1.606	321.7
C3	18.23	97.6	22.75	290.9	1.604	323.3
LSD C	1.014	5.00	2.223	14.03	0.1145	20.11
A1B1	20.27	115.6	27.76	324.1	1.927	379.0
A1B2	18.61	109.7	24.54	309.9	1.823	339.0
A1B3	19.18	113.4	23.85	314.2	1.800	352.4
A2B1	17.73	94.6	23.62	288.3	1.650	345.8
A2B2	16.99	95.7	21.74	286.7	1.573	318.1
A2B3	18.40	98.7	22.38	291.3	1.540	325.1
A3B1	12.75	73.4	18.27	254.3	1.120	249.9
A3B2	14.72	80.1	17.06	261.3	1.427	264.6
A3B3	15.38	83.5	16.03	263.0	1.330	269.1
LSD AB	1.613	7.62	4.200	12.07	0.2683	36.34
A1C1	17.69	109.0	23.90	309.5	1.790	347.2
A1C2	20.74	115.9	26.41	322.4	1.887	357.6
A1C3	19.63	113.7	25.84	316.3	1.873	365.6
A2C1	15.82	88.7	19.76	276.7	1.537	312.3
A2C2	18.10	101.9	23.94	295.8	1.620	340.3
A2C3	19.21	98.3	24.04	293.8	1.607	336.3
A3C1	12.84	72.8	15.08	247.7	1.233	248.3
A3C2	14.15	83.3	17.92	268.2	1.310	267.1
A3C3	15.86	80.8	18.36	262.7	1.333	268.2
LSD AC	1.653	8.74	4.262	20.56	0.1951	33.27
B1C1	16.00	94.4	20.84	283.0	1.540	322.1
B1C2	17.06	95.5	24.89	293.9	1.590	324.3
B1C3	17.70	93.5	23.91	289.8	1.567	328.3
B2C1	14.45	86.6	18.92	273.1	1.537	288.7
B2C2	17.67	101.3	22.29	295.0	1.647	310.4
B2C3	18.19	97.8	22.13	289.8	1.640	322.6
B3C1	15.90	89.6	18.97	277.8	1.483	297.0
B3C2	18.25	104.4	21.09	297.5	1.580	330.5
B3C3	18.81	101.5	22.19	293.1	1.607	319.1
LSD BC	1.694	7.88	3.721	20.95	0.2312	35.39

*A1: Irrigation according to the plant and soil's need for field capacity. A2 Irrigation 3 days after the plant and soil's need for field capacity. A3 Irrigation 6 days after the plant and soil's need for field capacity. *B1: Comparison treatment: NPK & Urea. B2: palm frond residues 40 tons. ha⁻¹ with (25% NPK and Urea) + B3 rice residues 40 tons. ha⁻¹ with (25% NPK and Urea). * C1: Control treatment (without addition) C2: Trichoderma 10 g. C3: Mycorrhizae 10 g.

fertilizer treatments showed positive effects, as no significant differences were observed between chemical fertilization and no bio-fertilizer addition (B1C1) and plant residue and bio-fertilizer treatments (B2C2, B2C3, B3C2, and B3C3.)

The results of the three-way interactions of the study factors in Table 4 showed positive effects at the treatments of delaying irrigation for 3 days, addition plant residues (palm fronds and rice), and addition bio-fertilizers (Trichoderma fungus and mycorrhizal fungi) A2B2C2, A2B2C3, A2B3C2, and A2B3C3, as it did not differ significantly when compared with the treatment of normal irrigation, addition chemical fertilizer, and not addition bio-fertilizers A1B1C1.

Table 4 shows the effect of the three-way interaction of irrigation intervals, plant residues, and bio-fertilizers in improving the growth and productivity of beet plant

Treatment	Number of leaves leaf plant ⁻¹ .	Chlorophyll content in leaves (mg/100g)	Dry weight of shoot (g)	Root weight (g).	Carbohydrate content of roots (micrograms g ⁻¹)	Alpha-lipoic acid estimation in root (microgram)
A1B1C1	18.79	114.6	26.27	320.4	1.900	376.3
A1B1C2	20.55	116.5	28.99	328.6	1.950	377.2
A1B1C3	21.46	115.5	28.01	323.5	1.930	383.5
A1B2C1	16.58	104.9	22.35	300.1	1.740	322.6
A1B2C2	20.97	113.6	26.05	318.3	1.890	341.9
A1B2C3	18.28	110.8	25.23	311.2	1.840	352.5
A1B3C1	17.69	107.6	23.07	308.2	1.730	342.7
A1B3C2	20.70	117.7	24.19	320.2	1.820	353.8
A1B3C3	19.15	114.8	24.29	314.2	1.850	360.7
A2B1C1	16.59	95.1	20.80	280.8	1.610	344.5
A2B1C2	18.26	94.8	25.52	293.1	1.690	345.2
A2B1C3	18.35	93.8	24.54	291.0	1.650	347.6
A2B2C1	14.38	84.2	18.88	272.6	1.510	287.7
A2B2C2	17.08	103.9	23.58	294.8	1.620	328.0
A2B2C3	19.50	99.0	22.76	292.7	1.590	338.6
A2B3C1	16.49	86.9	19.60	276.6	1.490	304.7
A2B3C2	18.95	107.0	22.72	299.7	1.550	347.8
A2B3C3	19.77	102.1	24.82	297.6	1.580	322.7
A3B1C1	12.61	73.5	15.45	247.8	1.110	245.5
A3B1C2	12.37	75.3	20.17	260.0	1.130	250.4
A3B1C3	13.28	71.3	19.19	255.0	1.120	253.8
A3B2C1	12.40	70.6	15.53	246.6	1.360	255.9

A3B2C2	14.97	86.3	17.23	271.8	1.430	261.2
A3B2C3	16.79	83.5	18.41	265.6	1.490	276.8
A3B3C1	13.51	74.3	14.25	248.6	1.230	243.5
A3B3C2	15.10	88.5	16.37	272.7	1.370	289.9
A3B3C3	17.52	87.6	17.47	267.6	1.390	273.9
LSD ABC	2.894	14.04	6.66	36.04	0.3767	59.66

*A1: Irrigation according to the plant and soil's need for field capacity. A2 Irrigation 3 days after the plant and soil's need for field capacity. A3 Irrigation 6 days after the plant and soil's need for field capacity. *B1: Comparison treatment: NPK & Urea. B2: palm frond residues 40 tons. ha-1 with (25% NPK and Urea) + B3 rice residues 40 tons. ha-1 with (25% NPK and Urea). * C1: Control treatment (without addition) C2: Trichoderma 10 g. C3: Mycorrhizae 10 g.

Discussion

The results in Table 3 indicate that the individual effects treatment for irrigation intervals A1 significantly outperformed most of the studied traits, this may be attributed to the fact that optimal irrigation tailored to plant growth requirements and soil field capacity led to increased relative humidity during growth stages, This reduced water potential between leaves and roots thus minimizing water loss, which helps the plant maintain cell turgor pressure within its tissues resulting in increased photosynthetic efficiency and enhanced effectiveness of all vital processes. Water acts as a reducing agent and the essential medium for all reactions occurring in the plant. Adequate humidity contributes to increased efficiency of vital processes and activates enzyme activity, positively effecting the production of bioactive compounds such as alpha-lipoic acid. The presence of adequate moisture in the plant has a direct effect on increasing growth through cell division and elongation, thus increasing food production, carbohydrate accumulation, and the dry weight of shoot, Adequate moisture it is a necessary factor in the development of the plant's shoot as it directly contributes to

increasing the number of leaves and chlorophyll content in leaves[55], this may be due to water's role in maintaining cell turgor pressure which increases cell division and differentiation and enhances meristematic activity, encouraging the growth of apical buds and the formation of new leaves. Water also plays a fundamental role in the absorption and transport of important nutrients including nitrogen and magnesium which are essential components of the chlorophyll molecule, all these indicators positively effect on root weight through the translocation of nutrients from the leaves to the roots, thereby increasing yield and plant productivity [53]. While a decrease in the average number of leaves, dry weight of shoot, and chlorophyll content in the leaves was observed when irrigation was delayed according to the plant and soil's needs from the field capacity requirements for treatments A2 and A3, this also affected other qualitative and chemical traits such as the carbohydrate content of the roots due to reduced carbon metabolism and food production, Similarly alpha-lipoic acid levels decreased due to inhibition of its biosynthetic pathways causing to a reduction in its concentration, this also resulted in a decrease

in root weight negatively affect plant productivity and total yield, the reason for this is that insufficient soil moisture may reduce water absorption by the plant causing increased water stress and decreased cellular turgor pressure. Consequently, this limits cell division and elongation slows the formation of new leaves, reduces photosynthesis, and hinders CO₂ uptake due to stomata closure. Furthermore, it negatively affects the shoot, reducing chlorophyll content in the leaves and causing yellowing due to water stress, This stress leads to chlorophyll breakdown caused by the formation of oxygen free radicals which are incompatible with ideal growth conditions, As a result food production in the leaves decreases, leading to a reduction in the dry matter of the shoot and decreased availability of nutrients Soil especially nitrogen, phosphorus and potassium, which reduces the absorption and assimilation by the plant [3][4].

As shown in Table 3, the chemical fertilizers NPK and Urea significantly outperformed the individual treatments in most of the studied traits, this may be attributed to the readily available nutrients provided by chemical fertilization which are characterized by rapid absorption and high solubility and the Adding in appropriate quantities increases the plant's mineral content which is consistent with [44] [51]. It also enhances the activity of vital processes, formation a new leaves, formation nucleic and amino acids and protein materials that help the plant form new cells and organs. It also increases the formation of chlorophyll pigment in the leaves by increasing the efficiency of magnesium absorption which is the basic component of the chlorophyll molecule, thus raising the levels of carbon metabolism and consequently increasing the manufactured materials that increase the dry matter of shoot system [48]. High levels of nitrogen and phosphorus lead to increased potassium concentration in leaves, potassium plays an essential and direct role in the transport of sugars, carbohydrates, and nutrients from the leaves to the roots. It also

increases the activity of essential enzymes in metabolic and transport reactions and reduces water loss through its presence in the guard cells of the stomata which regulate osmotic pressure in leaves under conditions of water stress. The increase in carbohydrate content in roots is also attributed to the increased number of leaves and chlorophyll content, this leads to an increase in processed food transported to the roots resulting in increased root weight and consequently higher plant productivity. Plant residues also enhance the activity of microorganisms including fungi by Maintaining the moisture necessary for growth, thus increasing the plant's ability to absorb essential macronutrients for vital processes within the plant [50] [54].

Table 3 shows positive results from the dual interaction treatments using plant residues and bio-fertilizers when irrigation is delayed, these treatments recorded an increase in most of the studied traits and no significant differences were observed when compared with chemical fertilization and full irrigation, this can be explained by the fact that the soil's ability to retain water may increase the effectiveness of microorganisms by creating a suitable environment for growth such as fungi, which leads to an increased supply of the plant with the elements necessary [14]. the increased carbohydrate levels in the roots under water stress conditions may be attributed to the use of plant residues such as palm fronds and rice which Maintaining moisture, additionally, bio-fertilizers like Trichoderma and Mycorrhizae improve the soil's physical, chemical, and biological properties by decomposing these residues and releasing nutrients in addition to secreting substances that stimulate plant growth and development which increases the availability of nutrients, nitrogen and phosphorus levels rise in the leaves, these elements are the basic component in the structure of amino acids, proteins, and nucleic acids which have an important role in the process of manufacturing food necessary for plant growth. Also the availability of

potassium works to transfer sugars and carbohydrates from the leaves to the roots [8] [34]. Nitrogen is available in the soil through the Trichoderma fungus which decomposes organic matter and Mycorrhizal fungi also have the ability to lower soil pH and dissolve complex organic phosphorus, converting into absorbable mineral form through the microorganism ability to secrete organic acids that dissolve phosphorus. Given the importance of phosphorus in the formation of nucleic acids and energy compounds which are essential for plant functions such as photosynthesis and respiration, this leads to an increase in vegetative traits such as the number of leaves and the dry weight of shoot system, consequently, root weight and plant productivity increase. The high chlorophyll content in leaves may be attributed to the availability of sufficient nitrogen which is fundamental for the formation of amino acids and enzymes involved in chlorophyll synthesis within the chloroplasts. The increased carbohydrate content in roots as shown in Table 3, may be due to the increased potassium content in the leaves, Potassium acts as a transporter of organic acids and total and reducing sugars to the roots [19] [23]. The increased root weight may be attributed to the role of plant hormones, auxin and gibberellin play a fundamental role in cell division and elongation which leads to an increase the cell size and consequently root weight. Nitrogen plays an important role in increasing plant hormones by enhancing the cells' ability to activate genes that increase amino acid synthesis, particularly tryptophan, the primary initiator to auxin, and mofalonic acid, the primary initiator to gibberellin [35].

The increased concentration of alpha-lipoic acid in the roots as shown in Table 3 when irrigation is delayed to the plant's need for treatments A2B2 and A2B3, may be due to water scarcity conditions as this acid increases as a result of water stress, because it acts as an antioxidant and resists oxygen free radicals and contributes to protecting cell membranes

and enzymes from oxidative damage, or may be due to an increase in vegetative growth, which increase the area exposed to light leading to increase food production and synthesis and transport of active compounds to the roots[30]. The increase may be attributed to the role of plant residues and bio-fertilizers in improving soil condition supply the plant with the nutrients necessary to build these active compounds, it may also be associated with increased biological processes that raise the concentration of alpha-lipoic acid in the roots by increasing nitrogen and phosphorus which enhances gene expression processes by producing amino acids responsible for building proteins that form octanoic acid, this octanoic acid is linked to the fatty acid transporter protein (ACP) within the mitochondria, which are the basic building blocks of these active substances that contribute to increasing the nutritional value of the crop [7].

The reason for the increase the number of leaves, dry weight of shoot system, chlorophyll content of the leaves, and root weight may be due to the effect of Trichoderma asprellum fungi added to the soil which enhances the efficiency of nutrient absorption by breaking down organic matter in the soil such as palm frond and rice residues and secretes some stimulating substances such as hormones and enzymes that increase the release of nutrients [25]. It also covers the plant roots and forms fungal hyphae around roots that dissolve complex compounds using organic acids that are formed during the decomposition of organic matter such as chloronic, lysinic, and humic acids and inorganic acids such as nitric, sulfuric, and phosphoric acids which are converted into compounds that are easily absorbed by the plant [16]. It also performs a defensive mechanism that protects the roots from pathogenic organisms in the soil by competing for food and space and produces antibiotics that regulate the microbial community in the soil, thus reducing the spread of harmful

organisms which leads to raising the growth indicators of the plant and improving the plant's nutritional status, thus increasing the production of active substances [56.]

Mycorrhizal fungi also have a positive symbiotic relationship with roots as it increases the absorption and accumulation of nutrients through the fungus's external hyphae, it has the ability to absorb phosphorus from the soil and transport it to the roots. it also improves the plant growth environment by promoting soil structure, increasing soil particle aggregation, and raising moisture retention level. Mycorrhizal fungal hyphae increase the root system's ability to absorb essential growth nutrients by extending to areas beyond root reach, it's also plays a role in improving water balance especially when plant residues are added to the soil which increases fungal activity this makes the plant more tolerant of drought and water stress in desert areas when irrigation is delayed from the plant's field capacity needed, thus helping to reduce water waste and build a sustainable environment [17] [22] [41], it also has the ability to secrete the enzyme phosphatase and form organic acids such as carbonic acid (H_2CO_3) which lowers pH soil. Furthermore, fungi can supply plants with significant quantities of nutrients such as nitrogen, phosphorus, and potassium, this leads to increased vital processes within the plant, [9] [20] [42.]

Table 4 indicates that the three-way interaction of the study factors delaying irrigation for 3 days, adding palm frond and rice residues, and adding Trichoderma and mycorrhizal fungi resulted in positive effects on all studied traits in treatments A2B2C2, A2B2C3, A2B3C2, and A2B3C3, these effects were not significantly different with full irrigation treatment, chemical fertilization (NPK urea) and not addition bio-fertilizers in treatment A1B1C1, this may be due to the interaction mechanism between plant residues and bio-fertilizers. Palm frond and rice residues played a fundamental role in

increasing the rates of most of the studied traits when combined with irrigation delay treatments, and its demonstrated a high capacity for retaining soil moisture. It also increases the effectiveness and activity of microorganisms and reduces the degree of soil reactivity which is directly proportional to the efficiency of bio-fertilizers which increase the availability of basic nutrients for all physiological activities such as respiration, photosynthesis. These elements are involved in the synthesis of nucleic acids (DNA and RNA) necessary for cell division, it also encourages the formation of chelated compounds with micronutrients which increases the absorption by the plant [26] [27] [32], in addition to the interaction with Trichoderma and Mycorrhizal fungi which have the ability to decompose plant residues and increase the availability of nutrients. Microorganisms are also important from an agricultural and fertility perspective, as contributes to reducing the excessive use of chemical fertilizers and irrigation water. The increase in vegetative, chemical, and qualitative traits in the three-way interaction treatments may be due to the cumulative effect of the study factors specifically the use of organic and bio-fertilization which improves the plant's nutritional status and consequently increases carbon metabolism and metabolic processes leading to higher levels of sugars, carbohydrates, and chemical compounds with specific qualitative traits [45] [58]. The above results are consistent with what was proved by [1] [5] [6] that the decrease in growth indicators due to delayed irrigation and its improvement with treatments of plant residues and bio-fertilizers may be due to the effect of these additions in retaining the moisture necessary for growth and thus raising the level of physiological and vital activities which is reflected positively in improving vegetative and qualitative traits. it also works to reduce the harmful effect of the spacing of irrigation intervals. This is what the results indicated when adding plant residues and bio-fertilizers in conjunction with irrigation intervals which

is contributed without significant differences

despite reducing irrigation water .

Conclusion

This study demonstrates that optimal irrigation scheduling combined with complete chemical fertilization achieves the highest levels of growth, productivity, and quality in beet plant. The key finding is that the negative impacts of moderate water scarcity (a 3-day irrigation delay) can be effectively mitigated through an integrated soil management strategy. The use of plant residues (palm fronds or rice at a rate of 40 tons h⁻¹) combined with bio-fertilizers (Trichoderma or mycorrhizal fungi) successfully maintained the plant's nutritional status by increasing all averages of the studied

traits to levels statistically equivalent to those achieved under optimal irrigation and complete chemical fertilization. This compensatory effect is attributed to the synergistic roles of organic amendments and beneficial microorganisms in enhancing soil water retention, and increasing plant stress tolerance. Consequently, reduced irrigation and reduced mineral fertilizers (75% of NPK and Urea), and use organic and biological inputs proves to be a practical sustainable alternative.

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