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EFFICIENCY OF BIOLOGICAL SOIL AMENDMENTS IN THE RECLAMATION OF SANDY SOIL FOR WHEAT CULTIVATION UNDER WATER STRESS CONDITIONS

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ABSTRACT: Sandy soils, with their inherent low fertility and poor water retention, pose substantial challenges to sustainable agriculture, particularly in arid regions such as Egypt. This study investigated the potential for reclamation of sandy soil for wheat cultivation using eco-friendly amendments. These include compost and a prepared fermented bio-liquid composed of seaweed extract, dairy byproducts, wood vinegar, and beneficial microbes. A two-year small-scale lysimeter experiment was conducted to simulate natural conditions. The first year served as a baseline (untreated soil as the control treatment). In the second year, all lysimeters were amended with green manure, compost, and the biological liquid soil conditioner. Key physical and chemical soil properties (texture, bulk density, porosity, pH, EC, and organic matter) were monitored. The biological yield of wheat was determined at various deficit irrigation levels (30%, 20%, 10%, and 0%) and three drought stress strategies (whole season, booting and heading stages, and maturity stage) in both untreated soil (1st year) and amended soil (2nd year). Wheat crop productivity increased significantly in the second year, particularly under moderate deficit irrigation, demonstrating the effectiveness of the amendments in mitigating water stress. The highest yield was obtained for the strategy of maturity stress, and the lowest yield was associated with the whole stress. The amendments mitigate the harmful effects of stress, particularly in cases of irrigation deficit (10%). The statistical analysis confirmed the significant effects of both the amendment and the irrigation level. This study introduces new and innovative green technologies that increase crop productivity and promote sustainable agriculture in water-scarce areas.

Keywords: Sandy soil, Compost, Biofertilizer, Deficit irrigation, Wheat yield.

INTRODUCTION

Agricultural productivity is severely hindered in sandy soils, which are often characterized by low fertility and poor water retention, particularly in areas with limited water supplies (Chen *et al.,* 2024). The reclamation of these soils for crop production requires effective soil management practices, such as applying soil amendments, to enhance their physical, chemical, and biological properties. This study investigates the effect of various soil amendments, including compost and biological fertilizers, on the rehabilitation of sandy soils for wheat cultivation (Komal *et al.,* 2025). This is due to its strategic importance, particularly under varying stress conditions (i.e., low soil fertility and poor water retention). Lysimeter experiments enable the simulation of the natural environment, utilizing un-reclaimed sandy soil, applying amendments, and adjusting irrigation levels, while collecting drainage water. The second-year treatments help to compare with untreated soil and assess the impact of these amendments on soil productivity.

Soil biological amendments (SBA) are biological materials of plant and animal origin added to un-reclaimed soil to improve its physical, chemical, and biological properties, ultimately enhancing plant growth and soil health (Srivastava *et al.,* 2014). These biological amendments aim to enrich the soil with organic matter, beneficial microorganisms, and essential nutrients, while also improving soil structure and water retention.

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The study's findings are expected to contribute to increased food security in arid regions, such as Egypt, by providing valuable insights into sustainable farming methods that enhance wheat production and improve the fertility of sandy soils. The research objectives are:

1. To evaluate the effect of different soil bio amendments (compost, biological fertilizers, and green manure) on the reclamation of sandy soil for wheat cultivation and production.
2. To investigate the impact of soil bio amendments on drought stress during different growth stages of the wheat crop grown in un-reclaimed and newly reclaimed sandy soil.

MATERIALS AND METHODS

Study Area

The study was conducted in the experimental station of the Department of Soil Sciences, Faculty of Agriculture, Menoufia University, Egypt, located at (30.5581 N, 31.0141 E).

Preparation of the Study Area

Thirty-six small-scale lysimeters were built using bricks and cement and were insulated with water-resistant material (cold bitumen). A slope was created at the bottom of each bed, with an opening connected to a short pipe, allowing for the appropriate slope to drain and collect any leachate. Each bed had a volume of 0.125 m³ (0.5 meters in length, 0.5 meters in width, and 0.5 meters in depth). Note: The total depth of the bed was 0.60 meters, but 10 cm was left from the top to facilitate irrigation. A wall of 30 cm width was left between the lysimeters for ease of walking, sampling, and conducting treatments. Watering connections and 120-liter tanks were installed to prepare and add liquid amendments for mixing with irrigation water.

The beds were filled with virgin sandy soil (never previously cultivated), sourced from a quarry in Shebin El-Kom, Menoufia Governorate (construction sand). The soil was thoroughly washed with tap water and left to dry, ensuring it was free from soluble salts and impurities. This process ensured that the beds contained only sand before being placed into the lysimeters. The soil is inferior in its fertility and properties, with unsuitable characteristics for cultivation, which was chosen to increase the challenge. If it were successfully reclaimed and cultivated within a short period, it would indicate the potential for success with other sandy soils, which generally have better characteristics. Wheat (a sensitive crop) was chosen for cultivation to increase the challenge further.

The first part of this experiment was conducted in the first year with the soil in its original state, without amendments. The treatments for deficit irrigation were applied at various stages. The second-year experiment focused on the addition of environmentally safe amendments to assess and evaluate the effects of improving soil properties on wheat productivity in sandy soils.

The lysimeters were filled with the sandy soil to a height of 0.5 meters. The soil's field capacity was calculated by adding excess water, measuring the drainage volume, and then subtracting the drainage volume from the total amount added. The result indicated that the soil's field capacity was 10% by volume. SBA was added to improve soil properties and make it more suitable for cultivation.

Seeds of Egyptian Clover were planted at a rate of 3 grams of seeds per bed, followed by irrigation with 3 liters of water per lysimeter to ensure enough water for this type of crop. The alfalfa was plowed into the soil to increase soil organic matter and enhance soil quality.

Vermicompost, characterized by the following analysis, was acquired from a local market in Egypt. It was applied to the surface layer (5-10 cm depth) at a rate of 600 grams per lysimeter.

Table 1: Chemical composition of the applied compost (ppm).

N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
1480.9	832.1	494.2	1079.1	1083.7	2218.7	215.7	13.7	137.9	44.4

Soil moisture content was measured using the TDR device (digital moisture sensor model 350).

Tanks with a capacity of 120 liters have been installed on a fence that is 2 meters higher than the lysimeters. The tank features a tap and a hose for adding the prepared liquid bio-amendment.

The preparation method for 25 liters of liquid biofertilizer

This liquid biofertilizer utilizes dried seaweed, a rich source of minerals, organic matter, and growth hormones, to enhance the structure of sandy soils, with a rate of 10g/L. Whey, a byproduct of fermented milk, is added at a rate of 20 ml/L, aiding in nitrogen fixation and soil health. A soil extract (200 g soil/liter water) containing Bacillus subtilis promotes plant growth and produces natural antibiotics that combat pathogens. Molasses (10 mL/L) is added to encourage the development of beneficial bacteria. Smashed potatoes (25 g/L) are boiled in water. Wood vinegar (30 ml/L) was added to prevent insect infection, lower the pH, enhance beneficial microbial activity, and decrease the presence of pathogens, fungi, and insects. The preparation process involves soaking dried seaweed in warm water for 24 hours, followed by the addition of whey, soil extract, potato suspension, wood vinegar, and molasses. The mixture is then stirred thoroughly and fermented for 2 days to activate the microbes.

This biological solution was used as a soil amendment and biofertilizer and was developed on the light of the following studies: Khan *et al.* (2009); Craigie (2011); Battacharyya *et al.* (2015); Lamont *et al.* (2017); Hong *et al.* (2020); Kloepper *et al.* (2004); Chen *et al.* (2007); Cawoy *et al.* (2011); Radhakrishnan *et al.* (2017); Ruzzi & Aroca (2015); Calvo, *et al.* (2014); Lashari *et al.* (2015); FAO (2013); NOFA (2018).

The soil in each treated lysimeter was amended with 0.5 liters of the bio-amendment three times, with a one-month interval between each addition.

Irrigation was performed using irrigation water mixed with biological fertilizer, after measuring the moisture content with a Time Domain Reflectometry (TDR) device and calculating the average moisture for all lysimeters.

Wheat (Egypt 1) was planted on December 1, 2022, and December 1, 2023, using a seeding method of 8 grams per lysimeter. Harvesting occurred on April 15, 2023, and April 15, 2024.

Irrigation treatments during the two studied years

Four deficit irrigation treatments (zero deficit or full irrigation, 10%, 20%, and 30% deficit). Three strategies for applying water stress according to the period of the entire growing season (whole stress or all-over the season, booting and heading stages or mid-season, and ripening or maturity). The very critical periods, such as germination, flowering, and grain filling, were avoided.

RESULTS AND DISCUSSION

Soil physical properties

Comparison of soil physical properties of experimental soil before treatments (1st year) and after treatments (2nd year) is presented in Table 2. The key parameters analyzed include particle size distribution, bulk density, real density, and total porosity.

Table 2: Physical analysis of the experimental soil before and after treatments.

Years	Particle size distribution				Texture	Bulk density g/cm^3	real density g/cm^3	Total porosity %
	C Sand	F Sand	Silt	Clay				
First	44.12	48.26	5.84	1.78	Sand	1.69	2.67	36.70
Second	41.1	47.36	8.24	3.30	Sand	1.51	2.67	43.45

Table 2 shows that the texture was classified as sand according to the USDA (2017), as the sand content exceeded 85%. After Treatment (2nd Year), the texture is still classified as Sand, but with an increase in silt and clay. The decrease in sand fractions (both coarse and fine) and increase in silt and clay suggest the possible addition of organic matter, which reduced sand dominance (Brady & Weil, 2016; and Zhao *et al.,* 2013). The slight increase in finer particles (silt and clay) may improve water retention (Omran *et al.,* 2023).

The results show unchanged real density and a decrease in bulk density in the second year compared to the first year. The reduction in bulk density suggests an improved soil structure, possibly due to the incorporation of organic matter (compost and bio-liquid amendment), which reduces compaction. This explanation aligns with that of Lal & Shukla (2004). Furthermore, the effect of root growth and biological activity enhances porosity (Six *et al.,* 2004).

The increase in porosity aligns with the decrease in bulk density, indicating better aggregation (Hillel, 2003). Sandy soils naturally have large pores, but the increase suggests that microporosity has improved with the addition of organic amendments (Lal, 2005).

Soil chemical properties

Table 3 presents the chemical properties of the experimental soil before treatment (1st year) and after treatment (2nd year). Key parameters analyzed include pH, electrical conductivity (EC), exchangeable cations, anions, and organic matter (OM).

Table 3: Chemical analysis of the experimental soil before and after treatments.

Years	pH	EC ds/m	Cations (meq/L)				Anions (meq/L)			OM %
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	CL^{-}	SO_4^{2-}	
First	7.99	0.23	0.8	0.45	1.02	0.03	0.31	1.01	0.99	0.09
Second	7.46	0.45	1.27	1.04	0.76	0.35	0.95	1.10	1.37	0.33

The detailed comparison shows a decrease in pH in the second year. This suggests a shift toward neutrality, possibly due to the addition of OM (e.g., compost, manure), which releases acidic compounds upon decomposition (Brady & Weil, 2016). The pH of 7.46 is closer to the optimal range (6.0–7.5) for most crops (Jones, 2003).

There is a rise in EC value, which is indicative of an increase in the quantity of soluble salts, potentially resulting from the breakdown of organic matter and the release of ions (Lal, 2005). Despite this, the USDA (2017) asserts that a salinity level of less than 1 dS/m is considered non-saline, meaning that an increase in salinity of this magnitude is still considered safe for most crops.

No noticeable change was observed in exchangeable cations and anions (meq/L) between the two years. This may be attributable to the exceedingly low cation exchange capacity of the sand.

According to Bationo *et al.* (2007), an increase in OM indicates the application of compost and the presence of clover below grade. The current value of 0.33% is still low, as the ideal range for most crops is 2–5% (Weil & Brady, 2017). This suggests that additional amendments are necessary.

The effect of the experimental treatments on the yield obtained over the two years was statistically analyzed. A complete randomized statistical analysis (two-way ANOVA) was performed in the first-year experiment to evaluate the effect of four levels of deficit irrigation (three levels compared to no deficit irrigation, control) as well as three strategies of deficit irrigation (entire-season deficit, mid-season deficit, and late-season deficit). The same analysis was repeated after reclamation in the second year. Also, a combined analysis (a three-way ANOVA) was performed to compare the observed differences in soil productivity between the two years. The results showed a significant effect of both deficit irrigation and strategy in the first and second years, with no significant interaction effect in the two years. The combined analysis showed a significant difference between the two years, with a remarkable improvement in the second year.

First-year data showed a highly significant effect (P = 0.000) of irrigation level, with an LSD of 0.03, and a significant effect (P = 0.036) with an LSD of 0.06 for water strategy (stress during wheat growth stages), with an insignificant interaction effect (P = 0.442).

Second-year data showed a highly significant effect (P = 0.000) of irrigation level with an LSD = 0.09, and an insignificant effect of water strategy (P = 0.51). The interaction was insignificant (P = 0.99).

The combined effect of the two years showed a very significant difference between the two studied years (P=0.000) with an LSD = 0.000. Significant effect of irrigation level was observed (P=0.000) with an LSD = 0.02. An insignificant effect was observed with the water strategy (P = 0.076). The double and triple interactions showed no significant effect (P = 0.248 for year and deficit, 0.959 for year and strategy, 0.893 for deficit and strategy, and 0.935 for the interaction of year, deficit, and strategy).

A two-year lysimeter study investigated the biological yield response of a crop grown in sandy soil with various irrigation regimes and soil conditions. The first year served as a baseline (untouched sandy soil), and the second year evaluated the impact of soil enrichment using a combination of green manure, compost, and a fermented liquid bio-amendment made up of seaweed extract, milk byproducts, wood extract, or vinegar, soil solution, sugar, and starch.

Figure 1 illustrates the effect of SBA and deficit irrigation on the mean values of the replicates for each treatment concerning the biological yield (in grams per plot) of wheat grown in sandy soil throughout two growing seasons. To simulate controlled irrigation conditions, the treatments were conducted in a lysimeter setup at 70%, 80%, 90%, and 100% FC.

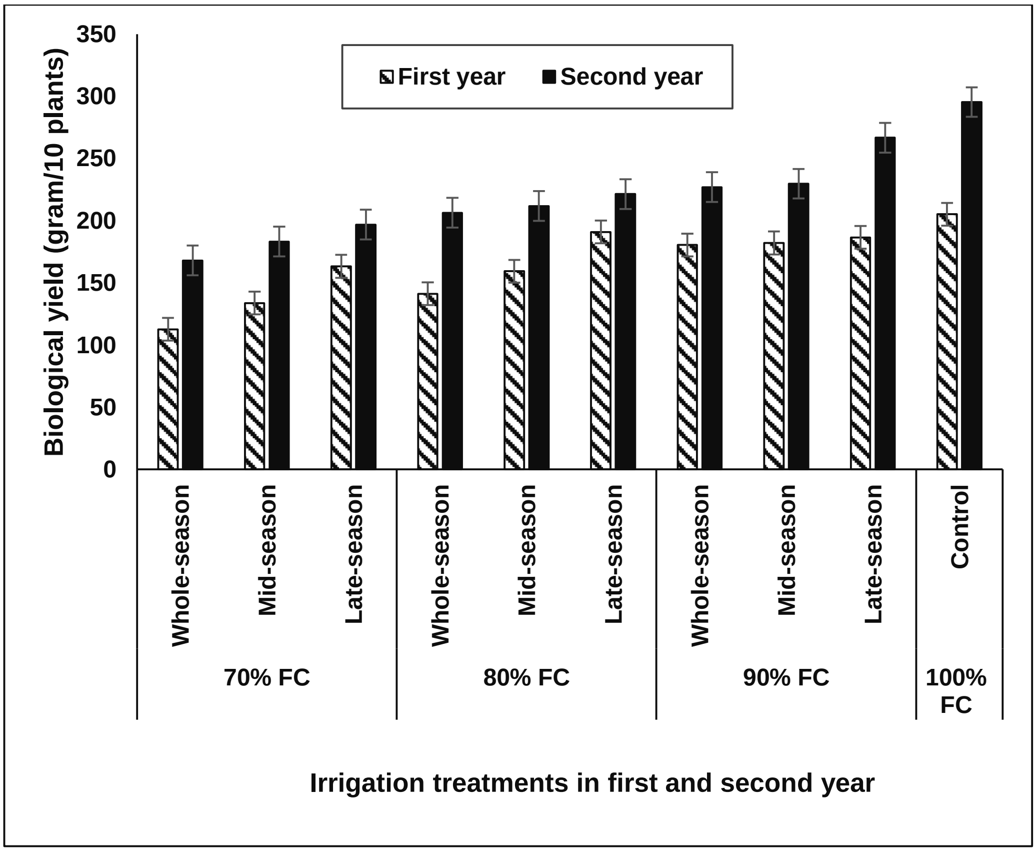

Fig. 1: Effect of SBA and deficit irrigation on biological yield in sandy soil over two growing seasons.

Figure 1 illustrates different treatments for each irrigation level, categorized by the timing of water stress: Whole-season, Mid-season, and Late-season. Compost and soil biological amendments (SBA) were applied in the second year.

The second year consistently exhibits a significantly higher biological yield than the first year for all irrigation treatments, as previously reported in the statistical analysis. This implies that bio-liquid and compost amendments have a beneficial impact on wheat productivity in sandy soils.

In this regard, Ghanem & El□Kharbotly (2020) noted that sandy soils possess a fundamental deficiency in organic matter, water, and nutrient retention, thereby inhibiting wheat cultivation. The incorporation of compost and plant-growth-promoting rhizo-bacteria (PGPR) has been suggested as a practical approach to mitigate these constraints and enhance productivity in water-deficient environments.

The biological yield rose as the irrigation level was raised from 70% to 100% FC. The control (100% FC) produced the highest yield, which was approximately 30 grams per plant, particularly in the second year.

An equivalent experimental condition was performed on wheat grown in sandy soil, with the soil enriched with compost and biological amendments under different irrigation regimes. The findings indicate that maximum grain and straw yields were achieved with full irrigation, while the use of amendments significantly improved yields compared to the control group. Furthermore, the amendments, especially under moderate water stress, resulted in negligible yield loss (Ghanem & El-Kharbotly, 2020).

This finding is consistent with earlier research, which has shown that optimal water availability improves biomass production (Fahad *et al.,* 2017).

For each irrigation level, the whole stress produced the lowest yield, especially in the first year. Water stress during the maturity stage had a lower negative impact than stress during the Whole or Mid periods. This is consistent with previous research, which has shown that water stress during the early and mid-growth stages has a greater impact on yield than late-season stress. Kang *et al.* (2002) reported that deficit irrigation during reproductive stages significantly reduced yield more than late-season deficit irrigation. By increasing soil water retention, amendments allow effective growth under reduced irrigation, supporting sustainable water use (Hossain *et al.,* 2017).

The use of compost and bio-liquid mitigated the effects of water stress in the second year, particularly during deficit conditions. According to Zhang *et al.* (2020), the amendments likely enhanced microbial activity, water retention, and nutrient availability, all of which contributed to improved plant productivity and health. Moreover, Seaweed extracts, beneficial bacteria (such as Lactobacillus and Bacillus subtilis), and wood vinegar are recognized as bio-stimulants that enhance nutrient cycling and root development and induce systemic resistance and stress tolerance (Khan *et al.,* 2009; Radhakrishnan *et al.,* 2017; El-Sayed *et al.,* 2022). Furthermore, organic amendments enhance soil carbon, which is crucial for carbon sequestration and long-term soil fertility (Rouphael *et al.,* 2018).

When water stress occurs, timing is crucial. Compared to earlier stress stages, harvest-period stress is less harmful and allows for more flexibility in irrigation management. In arid areas, incorporating bio-based amendments can enhance productivity and resilience, thereby advancing sustainable agriculture.

Table 4: Biological yield of wheat (g/plot) as affected by the application of irrigation deficit during various stages of wheat growth.

Treatment	deficit%	Whole		Mid		Late	
	%	g/pot	%	g/pot	%	g/pot	%
control	0	205.1	100.0	205.1	100.0	205.1	100.0
deficit 10	10	180.5	88.0	182.1	88.8	186.6	91.0
deficit 20	20	141.2	68.8	159.4	77.7	182.1	88.8
deficit 30	30	112.7	54.9	133.8	65.2	163.3	79.6
Treated	0	295.3	100.0	295.3	100.0	295.3	100.0
deficit 10	10	227	76.9	229.7	77.8	266.7	90.3
deficit 20	20	206.3	69.9	211.8	71.7	221.4	75.0
deficit 30	30	168	56.9	183.2	62.0	196.8	66.6

Table 4 indicates that implementing the maximum irrigation deficit (30%) during the late (maturity) stage of wheat growth led to the minimum reduction in biological yield compared to other stages, with the yield reaching nearly 80% of its value in untreated soil. In contrast, it constituted merely 67% of the SBA-treated soil.

The biological yield of the SBA-treated soil exceeded that of the untreated soil by 30%. The most significant decrease in biological yield occurred with a 30% irrigation deficit applied throughout the entire season, resulting in a yield of 55% of the untreated soil control and 57% for the SBA-treated soil. The incorporation of organic amendments rendered the wheat crop more susceptible to water deficit.

The implementation of irrigation deficit during the mid-stage of the wheat growing season resulted in a moderate yield reduction, with the most significant deficit decreasing yield by 35% in untreated soil and 38% in SBA-treated soil.

Figure 2 illustrates that the relationship between the biological yield of wheat and the percentage of irrigation deficit exhibits diminishing returns. This relationship can be represented as a polynomial of the second or third order with an R^2 value of one. The lower curve represents the entire season, the middle curve represents the intermediate stage, and the upper curve represents the late stage. All three curves are related to the entire season.

Figure 3 illustrates that the relationship between the biological yield of wheat and the irrigation deficit percentage in sandy soil treated with SBA is a decreasing one, which can be expressed as a third-order polynomial with an R^2 value of unity. The lower relationship applies to the entire season, the middle one to the intermediate stage, and the upper one to the late stage. A correlation factor of unity indicates the possibility of predicting yield at different deficit rates. The lowest relation is for the whole season, while the second is for the middle stage, and the upper relation represents the late or maturity stage. All three relations indicate reducing the crop with increasing the ratio of deficit.

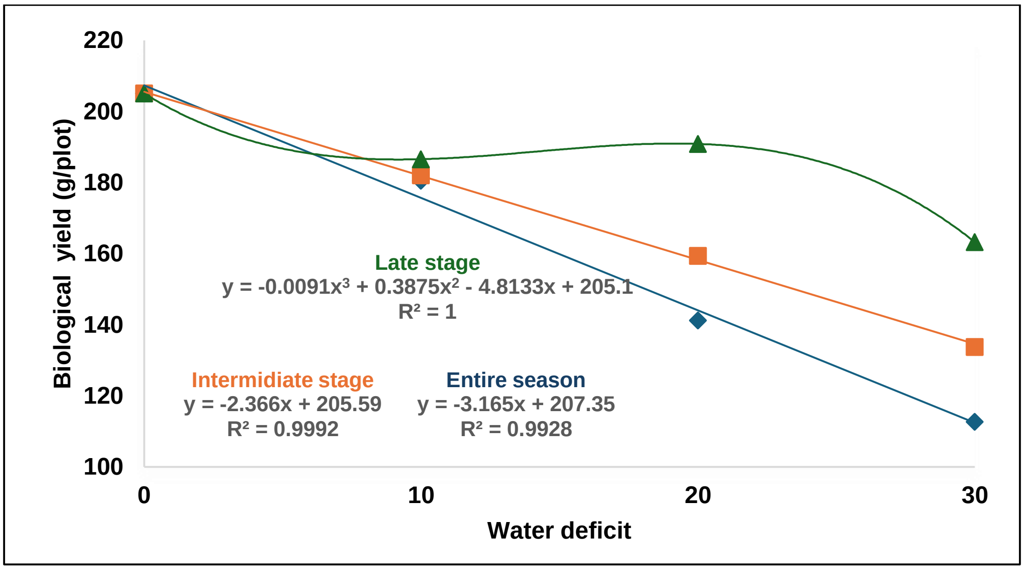

Fig. 2: Effect of deficit irrigation on the biological yield of wheat in untreated sandy soil at three stages of growth in the first year of the experiment.

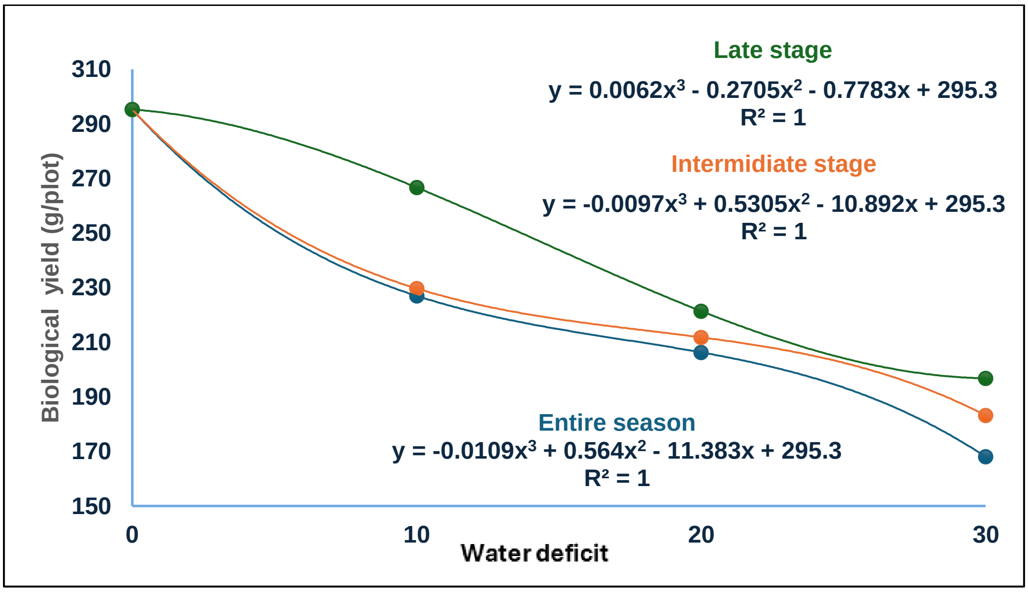

Fig. 3: Effect of deficit irrigation on the biological yield of wheat in sandy soil treated with SBA at three stages of growth in the second year of the experiment

Conclusion

Farmers in arid and semi-arid regions can improve drought resilience by blending compost with green manure and bio-based liquid amendments (a mixture of fermented liquid made up mainly from dairy waste, seaweed biomass, and sugar industry byproducts). Deficit irrigation can conserve water without compromising yield, and locally available organic waste can be used to prepare low-cost, sustainable fertilizers. Periodic assessments of soil organic matter, EC/pH, and microbial activity should be integrated into field management to monitor amendment efficiency. This soil amendment strategy aligns with clean agriculture principles and offers multiple environmental benefits. It minimizes chemical dependency and recycles bioresources, making it ideal for organic-certified systems. The bio-amendment-treated soil showed a 30% higher biological yield than the untreated soil. Applying irrigation deficit at the late stage of wheat growth resulted in the lowest reduction of biological yield compared to other stages.

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كفاءة المصلحات الحيوية للتربة في تحسين استصلاح التربة الرملية لزراعة القمح تحت ظروف الإجهاد المائي

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الملخص العربى

تُعدُّ التربة الرملية، نظرًا لانخفاض خصوبتها وضعف قدرتها على الاحتفاظ بالماء، من أكبر التحديات التي تواجه الزراعة المستدامة، خصوصًا في المناطق الجافة مثل مصر، ويهدف هذا البحث إلى دراسة إمكانية استصلاح التربة الرملية لزراعة القمح باستخدام محسنات صديقة للبيئة، شملت الكمبوست ومحاليل حيوية مُخمَّرة مكوَّنة من مستخلص الطحالب البحرية، ومخلفات الألبان، وخل الخشب، وبكتيريا نافعة.

تم إجراء تجربة ليزيمترات صغيرة الحجم على مدار عامين وذلك لمحاكاة الظروف الطبيعية. خُصص العام الأول كمعاملة مقارنة (تربة غير معالجة)، بينما في العام الثاني تم حرث السماد الأخضر في التربة واستخدم معه الكمبوست والمحلول الحيوي لجميع الليزيمترات.

تمت متابعة الخصائص الفيزيائية والكيميائية للتربة (مثل القوام، الكثافة الظاهرية، المسامية، رقم ال pH، التوصيل الكهربي EC، والمادة العضوية OM)، بالإضافة إلى قياس المحصول البيولوجي للقمح تحت مستويات مختلفة من تناقص الري (٠%، ١٠%، ٢٠%، ٣٠%)، وثلاث استراتيجيات للإجهاد المائي (خلال الموسم كله، في مرحلتي طرد وتكوين السنابل، وفي مرحلة النضج) في كلٍّ من التربة غير المعاملة (السنة الأولى) والتربة المعاملة (السنة الثانية).

أظهرت النتائج زيادة ملحوظة في إنتاجية القمح في السنة الثانية، خصوصًا تحت ظروف الري الناقص المعتدل، مما يعكس فعالية المحسنات في تقليل تأثير الإجهاد المائي، وقد تحقق أعلى محصول عند تطبيق الإجهاد في مرحلة النضج، بينما كان أدنى محصول عند تطبيق الإجهاد طوال الموسم، ولقد ساعدت الإضافات الحيوية على التخفيف من التأثيرات السلبية للإجهاد، خاصةً عند نسبة الري الناقص معاملة ١٠%، وأكد التحليل الإحصائي الأثر المعنوي لكلٍّ من معاملات التحسين ومستويات الري.

تُقدِّم هذه الدراسة تقنيات حيوية مبتكرة وصديقة للبيئة تُسهم في زيادة إنتاجية المحاصيل وتعزيز الزراعة المستدامة في المناطق شحيحة المياه.