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Correlation of Chlorophyll Fluorescence Parameter Fv/Fm with Physiological Development and Grain Yield in Local Wheat Cultivars (*Triticum aestivum L.*) Under Water Deficit Stress in South Iraq

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Abstract

This investigation aims to reveal the physiological responses of two local wheat cultivars (*Triticum aestivum L.*) to grain yield strived under the extreme conditions of desert environments. In arid and semi-arid regions where contemporary civilization relies on agriculture, we used a Chlorophyll Fluorometer linked to the WinControl-3 software, which enabled us to monitor the health status of the plant accurately. Conventional methods of assessing the health of the crops are beneficial to endeavor, but an infusion of technology as such enables effective resource management while increasing the efficiency of monitored physiological changes. We noted that with critical modular water deficit stress during vital stages of development, there is not a marked reduction in grain yield. The yield data collected at the end of April for the BUHOTH 22 cultivar reveals that the yield for the 6-day irrigation interval was 552 g/m², resulting in a total of 1380 kg for 2500 m². The parameter of fluorescence Fv/Fm was found to be the most important marker able to differentiate the physiological state over a period of time. This parameter is significant as it raises the standard of care and management of plants and determines the optimum irrigation proviso for arid regions, improving the yield of such areas. This study highlights the link between physiological changes in the plant life cycle and grain yield under water deficiency, emphasizing the need to integrate these physiological components into agricultural management strategies. Identifying these correlations enables farmers to swiftly address challenges in their work.

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Introduction

Wheat (*Triticum aestivum* L.) is one of the most widely cultivated cereal crops globally, serving as a fundamental source of nutrition for billions of people. With a cultivation history that spans thousands of years, wheat provides essential carbohydrates, proteins, and dietary fiber, making it a staple food in many cultures (Khalid et al., 2023). The growth and productivity of wheat are significantly affected by environmental factors, including temperature, humidity, and soil conditions (Huang et al., 2024). However, various abiotic stresses, particularly water scarcity, pose substantial challenges to wheat cultivation, especially in arid and semi-arid areas such as South Iraq. Drought stress is a critical factor that adversely affects the growth, development, and reproductive success of wheat. The interaction of climate, soil quality, and environmental stressors can lead to reduced yields and compromised crop quality (Zia et al., 2021). In South Iraq, where water resources are limited and rainfall is erratic, the impact of drought on wheat production is particularly pronounced. Traditional agricultural systems such as irrigation, soil reclamation, and the application of fertilizers have been employed to mitigate these challenges. However, as water scarcity becomes increasingly severe due to climate change, there is a pressing need to find out sustainable agricultural practices that can enhance the resilience of wheat crop. In recent decades, there has been a growing interest in the development of genetically tolerance wheat varieties, driven by the need for sustainable agricultural techniques that can withstand the pressures of climate change and resource scarcity (Yanagi, 2024). Breeding programs focused on drought tolerance aim to identify and incorporate traits that enable wheat to thrive under water-limited conditions. Among these traits, the chlorophyll fluorescence parameter Fv/Fm has emerged as a valuable indicator of photosynthetic efficiency and overall plant health, particularly under stress conditions. Understanding the relationship between Fv/Fm and physiological progress is essential for assessing the adaptability of local wheat cultivars to water deficit stress (Bartold and Kluczek, 2024). The Fv/Fm ratio reflects the maximum quantum efficiency of photosystem II, providing insights into the plant's ability to perform photosynthesis efficiently under drought stress conditions. Research has shown that variations in this parameter can correlate with other physiological traits, such as water absorption and transpiration efficiency, which are critical for drought stress tolerance (Hu et al., 2023). The physiological status of wheat plants, allowing for better management strategies under water deficit stress. Environmental stressors, particularly water deficit stress, are prevalent in agricultural landscapes. Water evaporation occurs when crop water uptake is insufficient to meet atmospheric demands, which is governed by root characteristics, soil properties, and atmospheric conditions affecting crop evapotranspiration (Nabhan et al., 2020). Grain yield serves as a key indicator of drought resistance, with genotype phenology also playing a significant role in wheat's yield potential under drought stress conditions (Ahmed et al., 2020). Understanding how these factors interact is crucial for developing effective management practices that can enhance wheat productivity in water-limited environments. Desert conditions present unique physiological challenges for wheat production, characterized by intense sunlight and elevated temperatures. Crop evapotranspiration (ET), particularly transpiration, is inversely related to grain yield in both C_3 and C_4 plants under low humidity conditions (Wang et al., 2023). Water deficit stress significantly reduces grain yield, particularly when crop cover is incomplete, which leads to increased soil water evaporation. Effective crop management practices are essential for enhancing grain yield in dryland agriculture, as soil water evaporation can account for more than 50% of ET (Yu et al., 2021). The harvest index, influenced by transpiration during the grain-filling period and the prevailing transpiration efficiency, indicates that maximizing yield potential requires careful management of water resources, particularly during critical growth stages (Yadav et al., 2024).The aim of this research is to investigate the correlation between the chlorophyll fluorescence parameter Fv/Fm, physiological aspects, and grain yield under water deficit stress conditions in local wheat cultivars (*Triticum aestivum* L.) in South Iraq. By focusing on the adoption of drought-tolerance wheat variety (BHOUTH 22) and efficient irrigation methods, this study seeks to provide actionable insights for farmers in the region.

Materials and Methods

Study Area:

The study area is located in the Basra province of Iraq, within the city of Zubair Al-Luhais, at geographical coordinates 30° 34’ 08” N and 46° 58’ 14” E, with average minimum temperature is around 14^{0}C and the average maximum temperature is around 27^{0}C. Spanning a total area of 0.25 hectares (2500 m²), this region is characterized by its sandy loam soil, which is renowned for its favorable drainage and nutrient-holding capacity, making it well-suited for diverse agricultural practices. The soil exhibits an electrical conductivity of 2.5 dS/m, indicating a moderate level of salinity, while the electrical conductivity of the water is recorded at 9.1 dS/m, suggesting the presence of soluble salts that could influence crop growth. The soil pH was measured at 7.61, which lies within the optimal range for many crops, thereby promoting nutrient availability and microbial activity.

Experiments:

To enhance organic matter, 50 kg of cow manure was applied across the 2500 m² area on November 1, 2023, enriching the soil with essential nutrients and improving its structure. Fertilization practices were carefully planned and implemented to enhance soil fertility and promote crop development. On November 23, 2023, 25 kg of DAP (Diammonium Phosphate) fertilizer per 2500 m² was applied using mechanical sowing methods, providing a quick source of phosphorus and nitrogen to the plants. This was followed by two applications of urea fertilizer on December 15, 2023; the first part consisted of 25 kg, and the second part included 40 kg, both per 2500 m². This strategic approach to fertilization aims to optimize nutrient uptake during critical growth stages. The cultivation process commenced on November 23, 2023, utilizing mechanical ploughing techniques to prepare the soil adequately for planting. This method not only creates a uniform seedbed but also ensures the effective incorporation of fertilizers into the soil. The choice of cultivation practices and the timing of fertilizer applications are crucial for maximizing crop yield and quality in this region, which is characterized by unique environmental challenges. Overall, this study area provides a representative setting for examining the effects of various agronomic interventions on crop yield in the context of Iraq's agricultural landscape. The field of study focuses on a local wheat cultivar, BHOUTH 22, with an average seed sowing rate of 50 kg per 2500 m^2, implemented through mechanical methods. This structured plot allows for detailed observation and analysis of the crop yield across the designated sections, facilitating a comprehensive assessment of the cultivars' growth and productivity. The field area is organized into 4 transects, with each transect measuring 625 m^2, the experimental field utilizes fixed sprinkler irrigation, equipped with a total of 24 sprinklers. To ensure even distribution of irrigation water, the sprinklers are spaced 12 meters apart in width and 18 meters apart in length, as illustrated in Figure 1. Irrigation was carried out systematically every 3 days and every 6 days to evaluate the differences among the various treatments in order to analyze the changes in chlorophyll levels and crop yield.

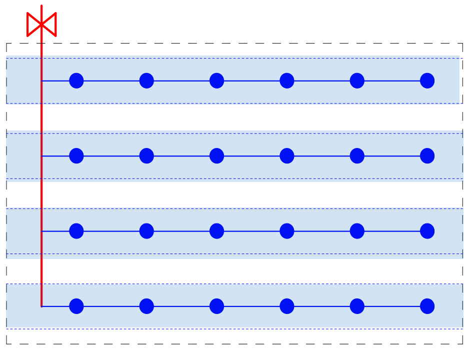

Fig 1: Layout of Experimental Field for Wheat Cultivar BHOUTH 22 and Irrigation System Design.

Measuring Soil Properties

Measuring soil properties is essential for effective soil management and ensuring optimal growth conditions for plants. To determine soil pH, a pH meter or test kit can be used by mixing a soil sample with distilled water in a 1:1 ratio. Electrical conductivity (ECe) is measured similarly, using the same soil-to-water ratio and an EC meter (Hendershot & Duquette, 1986). Total carbonate content can be assessed through an acid digestion method, where hydrochloric acid is added to the soil until effervescence stops (Nelson & Sommers 1982). Cation exchange capacity (CEC) is determined by saturating the soil with ammonium acetate and measuring the displaced cations (Thomas 1982). Organic matter content is evaluated using the loss on ignition method, where a soil sample is ignited at 360°C and weight loss is calculated (Walkley & Black1934). Chloride levels can be assessed using potentiometric titration with silver nitrate, while bicarbonate is measured through titration with a standard acid solution. For carbonate measurement, the acid digestion method is again employed. Magnesium and potassium are extracted using ammonium acetate, with magnesium analyzed through atomic absorption spectroscopy (AAS) and potassium measured using flame photometry or AAS. Nitrogen content is determined using either the Kjeldahl method or combustion method, while phosphorus is extracted using Bray or Olsen solutions and quantified through colorimetric analysis. Iron and zinc are extracted using DTPA and analyzed through AAS. Calcium is measured similarly to magnesium, and soil texture can be assessed using the hydrometer method or the feel method, which involves measuring sedimentation rates of different particle sizes (Soil & Plant Analysis Council, 2000).

Statistical Analysis

The collected data were analyzed using a two-way analysis of variance (ANOVA) with SPSS software (version 24). Significance between treatments was assessed using Student's t-test. The relationships among variables were evaluated through Pearson's correlation test.

Results and Discussion

Soil properties overview

The table 1 summarizes key soil properties, which are crucial for understanding soil health and fertility.

The soil properties indicate a moderately fertile environment that is well-suited for a variety of crops. The pH level of 7.61 suggests that the soil is slightly alkaline, which can significantly influence nutrient availability and microbial activity in the soil ecosystem. Alkaline soils can enhance the availability of certain nutrients, such as calcium and magnesium, while potentially limiting others, like iron and manganese, which are crucial for plant health. Therefore, monitoring pH levels is essential to ensure that all necessary nutrients remain accessible to plants (Msimbira & Smith, 2020). The electrical conductivity (ECe) is 2.50 dS/m. While some salinity can be beneficial, excessive levels may hinder plant growth by affecting water uptake and nutrient absorption. Plants may struggle to thrive in saline conditions, leading to reduced yields and compromised health. Proper irrigation practices and soil amendments are essential for managing salinity and maintaining a conducive growing environment.(Mannan et al., 2024). A total carbonate content of 120.00 g/kg may influence the soil's pH and overall chemistry. High carbonate levels can contribute to alkalinity, impacting the solubility of nutrients and thereby affecting plant growth. Understanding the carbonate dynamics is essential for managing soil fertility and ensuring that plants receive the required nutrients in

Table 1: physicochemical properties of the soil of study area's soil

Property	Value	Unit of Measurement
Soil pH	7.61	-
Electrical Conductivity (ECe)	2.50	dS/m
Total Carbonate Content	120.00	g/kg
Cation Exchange Capacity (CEC)	8.48	cmol/kg
Organic Matter	5.38	g/kg
Chloride (Cl)	10	mmol/l
Bicarbonate (HCO_3)	1.8	mmol/l
Carbonate (CO_3)	0	mmol/l
Magnesium (Mg)	3.1	mg/kg
Potassium (K)	52.10	mg/kg
Nitrogen (N)	0.35	mg/kg
Phosphorus (P)	114.35	mg/kg
Iron (Fe)	17.5	mg/kg
Zinc (Zn)	17.55	mg/kg
Calcium (Ca)	7.3	mmol/l
Soil Texture	Sandy loam	-

optimal proportions (Bolan et al., 2023). The cation exchange capacity (CEC) of 8.48 cmol/kg demonstrates the soil's ability to retain and exchange positively charged ions (cations), which are vital for nutrient availability. A moderate CEC indicates a reasonable capacity for holding essential nutrients such as potassium, calcium, and magnesium, making them available to plants. Enhancing CEC through organic matter addition can further improve nutrient retention and soil fertility (Adeyemo et al., 2023). The organic matter content of 5.38 g/kg is crucial for enhancing soil fertility and structure. Organic matter ameliorates water retention, increases microbial activity, and enhances nutrient cycling, all of which contribute to healthier plant growth. Additionally, organic matter plays a key role in soil aggregation, which improves soil aeration and drainage, further benefiting root development (Cotrufo & Lavallee 2022). The soil is classified as sandy loam, comprising 830 g/kg sand, 36 g/kg silt, and 134 g/kg clay. This texture provides an excellent balance between drainage and moisture retention, making it ideal for many agricultural practices. Sandy loam soils typically warm up quickly in the spring, allowing for earlier planting, while also retaining sufficient moisture during dry periods. This texture supports root penetration and facilitates healthy plant growth. Nutrient levels in the soil are also noteworthy. The presence of chloride (10 mmol/l) and bicarbonate (1.8 mmol/l) indicates specific ions that can affect soil chemistry and plant health. Adequate levels of essential nutrients include magnesium (3.1 mg/kg), potassium (52.10 mg/kg), nitrogen (0.35 mg/kg), phosphorus (114.35 mg/kg), iron (17.5 mg/kg), and zinc (17.55 mg/kg). These nutrients are critical for various physiological functions in plants. For instance, phosphorus plays a critical role in energy transfer and root development, while potassium regulates water uptake and enzyme activation. The presence of these nutrients suggests a favorable condition for plant growth, particularly with the sufficient phosphorus and potassium levels that support healthy development and high yields. Lastly, the calcium level at 7.3 mmol/l is important for maintaining cell wall structure and overall plant vitality. Calcium plays a crucial role in cell division and growth, and it helps in the formation of root systems, enhancing the plant's ability to absorb water and nutrients (Kisekka, 2024). The overall assessment of these soil properties indicates a healthy and fertile environment conducive to crop growth. However, it is essential to continuously monitor and manage factors such as salinity and pH to maintain optimal soil conditions. Implementing sustainable agricultural practices, such as crop rotation, cover cropping, and organic amendments, can further enhance soil health and productivity, ensuring long-term agricultural sustainability.

Yield Comparison of BUHOTH 22 Cultivar under Different Irrigation Intervals

The yield data collected at the end of April for the BUHOTH 22 cultivar reveals that the yield for the 6-day irrigation interval was 552 g/m², resulting in a total of 1380 kg for 2500 m². In contrast, the yield for the 3-day irrigation interval was slightly lower at 485 g/m², equating to 1212.5 kg for the same area. However, it is important to note that the differences in yield between the two irrigation schedules were not statistically significant at the 5% level. While 6 days' interval irrigations showed superiority under water stress condition. This suggests that both irrigation strategies can be effectively utilized without substantial impact on the overall yield of the BUHOTH 22 cultivar, providing flexibility for farmers in managing water resources (Alghawry et al., 2021).

Study of Chlorophyll Fluorometers

In this study, we investigated the effects of a fixed irrigation system combined with deficit irrigation technique on the physiological responses of wheat crop during its developing stage. Irrigation was scheduled every 3-days, with a specific deficit irrigation approach applied over two 6-day transects. This methodology allowed us to closely monitor crop health and plant responses under varying conditions.

To assess the health and photosynthetic activity of the plants, we utilized chlorophyll fluorometers, specifically the Junior-PAM, across 2 treatments. This instrument measures the fluorescence emitted by chlorophyll, providing valuable insights into the plant's overall condition and its ability to convert light energy into chemical energy (Tables 2 and 3); (Tolimir et al., 2024).

Relative Electron Transport Rate (ETR)

The relative electron transport rate (ETR) was calculated using the formula (Masojídek et al., 2001):

$$ETR=PAR\times ETR\text{-}Factor\times PpsII/Ppps\times Y(II)ETR=PAR\times ETR\text{-}Factor\times PpsII/Ppps\times Y(II) \quad (1)$$

This equation highlights the importance of the effective photochemical quantum yield of Photosystem II (PS II), denoted as Y(II). The ETR is influenced by the photon flux density (PAR) absorbed by PS II, which is critical for understanding the efficiency of photosynthesis. PpsII/Ppps means photon absorbed by PSII relative to photons absorbed by photosynthetic pigments.

PAR Considerations

For accurate ETR calculations, we relied on the PAR values provided by the Junior-PAM's internal settings, specifically calibrated for a 400 mm fiber at a distance of 1 mm from the sample. It is important to note that variations in illumination conditions can affect the PAR values used in the ETR calculations. Additionally, long-term use or potential defects in the light fiber may lead to decreased LED output, impacting the photosynthetic photon flux density (PPFD) delivered by the Junior-PAM (Schansker, 2020) (Tables 2 and 3).

Fluorescence Quotients

To further quantify the photochemical and non-photochemical losses of absorbed light energy, we derived fluorescence quotients from relative fluorescence yield measurements. These quotients include Fv/Fm and Y(II), which estimate the fraction of absorbed quanta utilized for PS II photochemistry (Schansker, 2020) (Tables 2 and 3).

Physiological Status of Local Cultivars

The physiological status of the local cultivar, BUHOTH 22, was assessed through the aforementioned measurements. The results provide insights into how these cultivars respond to different irrigation strategies and their overall photosynthetic efficiency, contributing to our understanding of their adaptability and health in varying environmental conditions (Tables 2 and 3). The findings indicate that the wheat cultivar subjected to water stress exhibited slight differences compared to those not exposed to such conditions, with cultivars adapted to desert environments demonstrating notable resilience to extreme conditions and limited water availability (Morsy et al., 2022). During the 6-day water stress exposure, the cultivar maintained a higher rate of photosynthetic activity and overall growth metrics, showcasing its superior

Table 2: BUHOTH 22 cultivar /3-days irrigation period interval, [WinControl (rev1219)]

No.	1:F	1:Fm'	1:PAR	1:Temp	1:Y (II)	1:ETR	1:Fo'	1:ETR-F.	1:qP	1:qN	1:qL	1:NPQ	1:Y (NO)	1:Y (NPQ)	1:Fo	1:Fm	1:Fv/Fm
1	126	429	0	37.2	0.706	0	0	0.84	0	0	0	0	0	0	126	429	0.706
2	171	368	125	36	0.535	28.1	120	0.84	0.794	0.182	0.557	0.166	0.399	0.066	126	429	0.706

Table 3: BUHOTH 22 cultivar /6-days irrigation period interval, [WinControl (rev1219)]

No.	1:F	1:Fm'	1:PAR	1:Temp	1:Y (II)	1:ETR	1:Fo'	1:ETR-F.	1:qP	1:qN	1:qL	1:NPQ	1:Y (NO)	1:Y (NPQ)	1:Fo	1:Fm	1:Fv/Fm
1	12	464	0	34.3	0.672	0	0	0.84	0	0	0	0	0	0	152	464	0.672
2	149	367	125	35.5	0.594	31.2	140	0.84	0.96	0.272	0.902	0.264	0.321	0.085	152	464	0.672

adaptation to drought. Remarkably, local variety, including BUHOTH 22, experienced only a minimal yield reduction of less than five percent (P_{Value} ≤ 0.05) allowing them to remain productive under stress. Furthermore, implementing water conservation strategies, such as deficit irrigation, yielded positive results, enhancing physiological activity and optimizing water use in these cultivars (Wang, et al., 2023). These findings underscore the potential of BUHOTH 22 for sustainable agriculture in arid regions, as their resilience can ensure food security and economic viability.

Conclusion

This study is concerned with the remarkable resilience of the BUHOTH 22 wheat cultivar during water scarcity conditions. It is evident that photosynthesis can still occur even under extreme water shortages resulting in minimal yield loss.. Adaptive soil properties combined with proper irrigation techniques significantly enhance water use efficiency. Physiological function is improved with deficit irrigation which, together with greater water use efficiency, promotes sustainable agricultural practices. This is crucial to food security in drought-prone regions, which is why the results of this study are very significant. Greater insights into these processes will improve the management of soil health, which, in turn, will lead to higher yields and more resilient agricultural systems. . Along with preserving the needed conditions for agriculture in this increasingly challenging climate, these findings highlight the necessity of integrating cultivars like BUHOTH 22 on a wide, if not global, scale for agricultural sustainability. So, to further augment crop production and water conservation, these drought tolerant varieties should be adopted but with scrutiny for implications in the seasons to come and the genetics behind them.

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