REDUCING WATER CONSUMPTION AND IMPROVING SOIL, ROOT QUALITY OF POTATO VIA ENVIRONMENTALLY SUSTAINABLE TREATMENTS

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ABSTRACT

The study aimed to improve potato plant productivity, roots growth biomass, and the efficiency of water utilization by using sustainable treatments. The experiment carried out at vegetable field of the College of Agricultural Engineering Sciences - University of Baghdad during spring season 2023. The experiment was conducted using split plot arrangement within Randomized Complete Block Design with two factors and three replicates (2X6X3). Applying TiO_2-NPs represented the first factor (main plot) (10 mg.L^{-1}), which symbolized (T_0, T_1). six treatments were included to represent subplots (regular irrigation interval (I) prolonged irrigation interval (D), fungal biofertilizers (D_B), fungal biofertilizers + mannitol (D_{BM}), fungal biofertilizers +xanthan (D_{BZ}), fungal biofertilizers + mannitol+ xanthan (D_{BMZ}). Results exhibited the superiority of spraying TiO2-NPs in all water use efficiency and yield traits. Also the results demonstrated the superiority of interaction treatment T_1D_{BMX} in producing significant results in nutrients concentrations and yield traits in compare to control treatment T_0D.

Keywords: Iraq; responsible consumption and production; biopolymer; mannitol; climate action, biofertilizers, xanthan gum; mycorrhizae; Trichoderma zero hunger

تقليل الاستهلاك المائي وتحسين التربة وجودة الجذور لنبات البطاطا من طريق معاملات مستدامة بيئياً

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المستخلص

هدفت التجربة الى تحسين خصائص نمو الجذور وانتاجية وكفاءة استعمال المياه لنبات البطاطا باستخدام معاملات مستدامة بيئيا ، نفذت تجربة حقلية في حقول كلية علوم الهندسة الزراعية/جامعة بغداد للموسم الربيعي 2023. طُبقت التجربة باستعمال تصميم القطاعات الكاملة المعشاة على وفق ترتيب القطع المنشقة بعاملين وثلاث مكررات (3X6X2)، فيما يخص العامل الاول فتم اضافة TiO_2–NPs بمستويين (0، 10مل.لتر$^{-1}$) والذي رُمز له (T_0 وT_1)، اما العامل الثاني فتضمن ست معاملات وزعت كقطع ثانوية كالاتي (ري طبيعي I، ري بمدة متباعدة D، اسمدة احيائية تحت ظرف الري المتباعد D_B، اسمدة احيائية تحت ظرف الري المتباعد+ مانيتول D_{BM} ، اسمدة احيائية تحت ظرف الري المتباعد+ صمغ الزنثان D_{BZ} ، اسمدة احيائية تحت ظرف الري المتباعد+ مانيتول+صمغ الزنثان (D_{BMZ}) . اظهرت النتائج التفوق المعنوي لرش TiO_2–NPs في جميع مؤشرات كفاءة استخدام المياه والحاصل، فضلا عن تفوق معاملة التداخل T_1D_{BMX} بإعطائها اعلى القيم لتركيز المغذيات في الاوراق والحاصل مقارنة مع معاملة الري المتباعد بدون اضافة T_0D.

الكلمات المفتاحية: العراق، الاستهلاك والانتاج المسؤولان، بوليمر حيوي، مانيتول، العمل المناخي، الاسمدة الاحيائية، صمغ الزانثان، القضاء على الجوع، مايكورايزا، ترايكوديرما.

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INTRODUCTION

Achieving carbon neutrality is a powerful approach to address challenges like global warming and severe climate events, such as drought (24, 35, 38, 39). Carbon neutralization refers to the process of balancing carbon emissions with carbon removal, achieving a net-zero carbon footprint (14, 15, 40). In agriculture; this involves both reducing emissions and enhancing carbon sinks that absorb CO_2 from the atmosphere ,such as carbon sequestration in soil (9, 23, 29). Potato (*Solanum tuberosum*) is a crucial staple crop worldwide, valued for its adaptability and importance as human food. However, drought poses a significant challenge to its cultivation, affecting growth, tuber quality, and yield. As water scarcity increases due to climate change, the potato's sensitivity to water stress threatens food security in Iraq (5, 27). Efforts to enhance drought resilience through sustainable management are critical (31). Biofertilizers enhance microbial activity, leading to greater stabilization of carbon in the soil (2, 16, 36). Studies indicate that biofertilizers can replace between 23% to 52% of mineral fertilizers without affecting crop yields, accordingly; lowering the overall carbon footprint associated with fertilizer use (30). Even more; the production of biofertilizers generates considerably lower carbon emissions compared to conventional fertilizers. For example, biofertilizers emit up to 23.2 times less carbon than nitrogen fertilizers and significantly less than organic fertilizers (17). There is a notable connection between the use of biofertilizers and crops production (4, 10, 18, 37). Higher yields were observed in conjunction with enhanced water use efficiency (WUE) via biofertilizers, indicating that biofertilizers not only promote plant development but also optimize the utilization of water resources (3, 32). Biopolymers are becoming more well-known in agriculture as environmentally friendly substitutes for traditional polymers (11). They come from natural sources and have a number of advantages, such as being biodegradable and having a less significant environmental effect (33). Xanthan gum has a strong affinity for water, which allows it to absorb significant amounts of moisture. This property contributes to its effectiveness in increasing the water retention capacity of soils (22). Tran et al. (34) reported that adding xanthan gum to soil improved its ability to hold onto water and made lawns more resistant to water deficits. In many plant species, mannitol, a sugar alcohol, is important for improving plant growth and water use efficiency (WUE), especially in stressful conditions like drought and salinity (1). Mannitol accumulation has been linked to enhanced resistance against oxidative stress in plants like *Olea europaea*. The ability of these plants to transport and utilize mannitol efficiently contributes to their overall water use efficiency (25). Titanium dioxide (TiO_2) nanoparticles have been studied for their impact on plant growth and water use efficiency in many researches (13, 21).TiO_2-NPs have shown to improve growth parameters and mitigate some adverse effects of limited water availability. For example, plants treated with TiO_2 showed improved gas exchange features even under water stress, indicating that TiO_2 can enhance plant resilience to drought conditions (20, 26). Consequently; the study seeks to optimize water management strategies and promote drought-tolerant tools to improve potato production resilience.

MATERIALS AND METHODS

Field preparation, planting, harvest

The experimental study took place at the research unite (A) of the College of Agricultural Engineering Sciences, University of Baghdad (Al-Jadiryah), during the spring of 2023. Table (1) presents the chemical and physical characteristics of the soil. Santana hybrid class (Elite) potato tubers were planted in a single row in the center of the furrows on January 28, 2023. There was drip irrigation installed in the field. Plants were spaced 0.25 meters apart from one another and 0.75m among rows. Planting density was 53333 $plant.ha^{-1}$. After 120 days of planting, every plot was harvested.

Experimental design

The experiment was implemented by using split plot arrangement within Randomized Complete Block Design with three replicates (2X6X3), in which titanium dioxide represented the main factor with two concentrations (0, and 10 mg.L^{-1}) which symbolized (T_0, T_1), six treatments were included to represent subplots (drought mitigation strategies DMS) (regular irrigation interval (I) (as control) (4 days), prolonged irrigation interval (D) (8 days) according to Al-Rubaie recommendation (7), fungal biofertilizers under (D), (D_B), fungal biofertilizers + mannitol under (D) (D_{BM}), fungal biofertilizers +xanthan under (D) (D_{BZ}), fungal biofertilizers + mannitol+ xanthan under (D) (D_{BMZ}). Titanium dioxide (nano-anatase) was applied three times following the growth cycle of the potato plant; specifically, the initial application occurred during the vegetative growth phase, the second application took place at the tuber initiation stage, and the final application was done during the tuber enlargement stage. Fungal biofertilizers (mycorrhizae *Glomus intraradices* + trichoderma *Tricoderma asperellum*) mixed with corn cobs residues (50 spores.1g^{-1}) and positioned as a pad beneath the tuber during planting in the soil at a dosage of 20g for each tuber. Xanthan gum mixed with the soil at 1% percent before planting. Mannitol injected three times at a concentration (30mM.L^{-1}) according to the mentioned potato growth cycle in rhizosphere zone.

Table 1. Physical and chemical properties of the soil

Character	Value
pH	6.16
$EC_{1:1}$ (ds.m^{-1})	390.8
Total N (mg kg^{-1})	53.8
P (mg kg^{-1})	12.5
K (mg kg^{-1})	168.8
Ca (mg kg^{-1})	185.8
Mg (mg kg^{-1})	168.8
Fe (mg kg^{-1})	1.4
Na (Meq L^{-1})	59.8
Cl^- (Meq L^{-1})	49.8
SO_4^{-2} (Meq L^{-1})	205.8
HCO_3^- (Meq L^{-1})	475.8
O.M. (%)	9.1
Gypsum (%)	318.8
Sand (%)	10.8
Silt (%)	38.8
Clay (%)	46.8
Texture	Clay loam

Study traits

Potato leaves concentrations from N,P,K were tested according to the methods of (19, 28, 12) respectively, water use efficiency traits were fixed as follows; roots biomass (g), water use efficiency (kg.m^3) (6), Leaf relative water content (RWC) (%) (8). The yield traits that determined were tuber diameter (cm), tuber length (cm), and marketable plant yield (g). The data were analyzed through analyses of variance and the averages were compared using L.S.D. test under 5% probability.

RESULTS AND DISCUSSION

Leaves N,P,K percents traits : Results in table 2 highlight that spraying Titanium dioxide (nano-anatase) has a potent impact on potato leaves N,K percents (2.194, 2.69%) respectively in compare to minimum percents found T_0 (1.902, 2.4%). Table 2 also exhibits that regular irrigation treatment (I) produced the highest N,K percents (2.267, 2.76%). Nevertheless; P, percent were significantly increased as a result of drought mitigating treatments. In fact; the most superior treatment is D_{BMX} (bifertilizer+ mannitol+ xanthan); (0.53%), in compare with the lowest traits with untreated plants under drought conditions which exhibit a discernible decline in each of the aforementioned traits. Interaction between titanium dioxide and drought mitigation treatments produces significant findings in entire nutrients percents, in which T_1I exhibits superiority in producing the highest N, K percents in potato leaves (2.4%, 2.9%) respectively. However; T_1D_{BMX} treatment doesn't significantly differ from T_1I (2.36, 2.86%) respectively. Even more; it exhibited excellence over all drought treatment in producing the highest P percent (0.556%). The lowest percents were found in T_0D.

Water use efficiency traits

Spraying TiO_2-NPs shows significant impact over none spraying in the entire water use efficiency traits (Table 3). T_1 produced the highest (67.39%, 11.6%, 7.087g) respectively in compare with the lowest in T_0. Drought mitigation treatments exhibit remarkable effectiveness across most traits for water use efficiency (Table 3). Plants treated with bio fertilizers, biopolymer, and mannitol under drought conditions significantly show superiority in water use efficiency and root dry biomass (12.86, 7.5) over all other treatments. While the lowest root biomass found in regular irrigated (I) (5.883), which produced the highest percent of leaves relative water content. The interaction between TiO_2-NPs and drought mitigation treatments doesn't reach to the significant level for the entire traits.

Table 2. Effect of titanium dioxide (T), and drought mitigation strategies (DMS): biofertilizers (B), mannitol (M), and xanthan gum (X) on potato leaves nutrients percents under drought conditions

traits treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)
		T	
T_{0} (control)	1.902	0.440	2.40
T_1	2.194	0.486	2.69
LSD(0.05)	0.021	N.S.	0.0208
		DMS	
I [irrigated (control)]	2.267	0.490	2.76
D [drought]	1.533	0.341	2.03
D_B	1.983	0.440	2.48
D_{BM}	2.117	0.473	2.61
D_{BX}	2.150	0.506	2.65
D_{BMX}	2.240	0.530	2.74
LSD(0.05)	0.086	0.0458	0.0865
		T X DMS	
T_0I (control)	2.133	0.523	2.63
T_0D	1.433	0.313	1.93
T_0D_B	1.734	0.390	2.23
T_0D_{BM}	1.967	0.423	2.46
T_0D_{BX}	2.033	0.490	2.53
T_0D_{BMX}	2.113	0.503	2.61
T_1I	2.400	0.456	2.90
T_1D	1.633	0.370	2.13
T_1D_B	2.233	0.490	2.73
T_1D_{BM}	2.267	0.523	2.76
T_1D_{BX}	2.268	0.525	2.77
T_1D_{BMX}	2.366	0.556	2.86
LSD(0.05)	0.112	0.0678	0.1120

Table 3. Effect of titanium dioxide (T), and drought mitigation strategies (DMS): biofertilizers (B), mannitol (M), and xanthan gum (X) on Water use efficiency traits of potato plant under drought condition

Traits treatments	Leaf relative water content (RWC) (%)	WUE ($kg.m^3$)	Roots dry weight (g)
		T	
T_0 (control)	65.44	9.90	6.567
T_1	67.39	11.60	7.087
$LSD_{(0.05)}$	0.733	0.790	0.3238
		DMS	
I [irrigated (control)]	71.83	9.91	5.883
D [drought]	58.67	8.59	6.033
D_B	64.00	9.36	6.917
D_{BM}	66.17	11.28	7.117
D_{BX}	68.67	12.50	7.400
D_{BMX}	69.17	12.86	7.583
$LSD_{(0.05)}$	0.783	2.305	0.5210
		T X DMS	
T_0I (control)	71.00	8.69	5.734
T_0D	57.67	7.08	5.932
T_0D_B	63.00	8.44	6.767
T_0D_{BM}	65.33	11.27	6.867
T_0D_{BX}	67.66	12.55	7.000
T_0D_{BMX}	68.00	11.37	7.100
T_1I	72.67	11.11	6.033
T_1D	59.65	10.10	6.132
T_1D_B	65.00	10.28	7.067
T_1D_{BM}	67.00	11.28	7.367
T_1D_{BX}	69.67	13.17	7.800
T_1D_{BMX}	70.33	13.62	8.067
$LSD_{(0.05)}$	N.S.	N.S.	N.S.

Table 4. Effect of titanium dioxide (T), and drought mitigation strategies (DMS): biofertilizers (B), mannitol (M), and xanthan gum (X) on yield traits of potato plant under drought conditions

Traits treatments	Tuber length (cm	Tuber diameter (cm)	Marketable plant yield (g)
		T	
$T_{0\ (control)}$	10.56	5.1	1211
T_1	10.92	5.6	1424
$LSD_{(0.05)}$	0.316	0.341	103.9
		DMS	
I [irrigated (control)]	10.58	6.1	1484
D [drought]	10.25	4.5	1011
D_B	10.83	5.3	1084
D_{BM}	10.84	5.4	1332
D_{BX}	10.84	5.4	1465
D_{BMX}	11.08	5.8	1527
$LSD_{(0.05)}$	N.S.	0.563	324.8
T_0I (control)	11.50	5.5	1308
T_0D	10.33	4.1	823
T_0D_B	10.67	5.1	968
T_0D_{BM}	10.68	5.2	1337
T_0D_{BX}	10.17	5.3	1493
T_0D_{BMX}	10.00	5.5	1333
T_1I	9.67	6.6	1660
T_1D	10.17	4.8	1198
T_1D_B	11.00	5.5	1200
T_1D_{BM}	11.00	5.6	1328
T_1D_{BX}	11.50	5.6	1561
T_1D_{BMX}	12.17	6.1	1597
$LSD_{(0.05)}$	1.194	0.651	N.S.

Yield traits

Table (4) displays significant impact of titanium dioxide spraying on all yield traits. T_1 shows superiority in tuber length, diameter and plant marketable weight (10.92cm, 5.6cm, 1424g) respectively when compared to the lowest in non-spraying (T_0). Table (4) as well describes that D_{BMX} treatment significantly superior in tuber diameter, and plant marketable weight (5.8cm, 1527g) respectively, while plants under prolonged irrigation (D) produced the lowest (4.5 cm, 1011 g) respectively. As for interaction between titanium dioxide and drought mitigation treatments; T_1I reveals superiority over all treatment producing the highest tuber diameter (6.6cm). While the longest tubers found in T_1D_{BMX} treatment (12.17cm). The application of titanium dioxide nanoparticles resulted in obvious enhancement in plant traits. This may be a result of its work in increase photosynthetic efficiency by promoting chloroplast development and enhancing the plant's ability to cope with drought stress (21). As for biofertilizers; they enhance nutrients availability (18), this can lead to improved growth and higher yields, even under limited water conditions. Even more; the application of biofertilizers promotes beneficial microbial communities in the soil. These microbes can improve soil structure, increase moisture retention, and enhance plant resilience to drought conditions (2). Additionally; plants treated with biofertilizers often exhibit physiological adaptations that improve WUE. For instance, they develop deeper root systems which allows for better water management during periods of stress (32).The presence of xanthan gum and mannitol sugar enhances the action of biofertilizers, since xanthan gum is a biodegradable soil amendment that could increase soil water capacity by 60% (33), making it particularly beneficial for maintaining soil moisture during dry spells. As for mannitol sugar; it acts as an osmolyte, helping plants to maintain turgor pressure during periods of water deficit (1). This osmotic adjustment is crucial for sustaining cellular functions and overall plant health under stress conditions.

In conclusion, preserving our natural resources is not just an environmental necessity but a moral obligation for future generations. By adopting sustainable practices, climate change in Iraq could be mitigated and ensure a thriving environment for decades to come.

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