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ROLE OF MANAGEMENT PARTIAL FURROW IRRIGATION, ORGANIC AND BIO FERTILIZERS ON WATER CONSUMPTIVE USE OF *ZEA MAYS* L. UNDER WATER SCARCITY

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ABSTRACT

A field experiment was conducted in the Yusufiyah region, Baghdad Governorate, to cultivate maize during the fall agricultural season of 2022. The study was designed using a randomized complete block design arranged in a split-plot layout with three replications. The main plots included different irrigation treatments: conventional furrow irrigation, alternate partial root-zone irrigation, and fixed partial root-zone irrigation. The subplots involved different fertilization treatments: mineral NPK fertilizer applied according to the recommended rate for maize, 50% mineral fertilizer combined with biofertilizer (Azotobacter chroococcum as nitrogen-fixing bacteria and Pseudomonas fluorescens as phosphate-solubilizing bacteria), 50% mineral fertilizer combined with natural organic fertilizer (Orgevit), and 50% mineral fertilizer combined with both the biofertilizer and the organic fertilizer. The organic and biofertilizer + 50% mineral fertilization treatment under alternate furrow irrigation recorded the lowest water consumption at 275 mm season^{-1}, followed by the organic fertilizer + 50% mineral fertilization treatment under alternate furrow irrigation, which recorded a water consumption of 310 mm season^{-1}. Water productivity values were 1.73, 2.95, and 1.97 kg m^{-3} for conventional furrow irrigation, alternate furrow irrigation, and fixed partial root-zone irrigation, respectively.

INTRODUCTION

Maize (*Zea mays* L.) is one of the strategic cereal crops in Iraq, ranking second in productivity after wheat. Statistical data indicate that the total maize production for both the spring and fall seasons reached 473.1 thousand tons during the summer season of 2019, marking an increase of 410 thousand tons compared to the previous season's production of 63.3 thousand tons. The average maize yield for both cropping seasons was estimated at 918.3 kg per dunum, based on the total cultivated area (Central Statistical Organization, Ministry of Planning, 2020). Biofertilization is therefore defined as the application of beneficial microorganisms in organic farming and constitutes one of the sustainable agricultural technologies for the accomplishment of increased soil fertility to achieve higher crop productivity. Bacteria, fungi, and algae, which help in mineralization processes and thus make nutrients available to plants through applying organic matter, accelerate the cycling of nutrients. Apart from playing a paramount role in nitrogen fixation with the atmosphere, biofertilizers help in the process of phosphorus, which is insoluble during its mineral phase. Also, they enhance soil structure and consequently enhance crop productivity and sustainability. Biofertilizers mean an alternative for low-cost, non-toxic sustainable agriculture practice against those chemical fertilizers; hence, they are not meant to replace them absolutely, but to accompany chemical fertilizers to make them effective with less environmental pollution. Unlike chemical fertilizers, biofertilizers unite a range of microorganisms with a vast community structure, well-oriented toward soil health and improved water retention capacities within soils, subsequently improving drought resistance of soils. Research output proved Azotobacter fixed 0.3 to 15 kg N ha^{-1} per year, thereby sparing urea inorganic nitrogen requiring fertilizers, increasing phosphorous availability, and synthesizing enzymes, hormones, and growth regulators useful to plant growth (Kumar *et al*., 2022; Aboohanah *et al*., 2022; Al-sudani *et al*., 2025; Jabbar and Ati, 2025).

ORGEVIT is an organic fertilizer based on biochar, obtained from the thermochemical conversion of biomass under limited oxygen conditions. Biochar is presented as a soil amendment in improving soil properties and resource use efficiency besides preventing environmental pollution and greenhouse gas emissions. More so, biochar plays a significant role in carbon storage and sequestration and may enhance soil improvement qualities through checking on emissions from the biomass decomposition processes, making it a fundamental practice of sustainable agriculture (Alburquerque *et al*., 2014; AbdulSayed and Al-Tameemi, 2019; Almoosa *et al*., 2025). Among the strategies in the improvement of maize productivity and stability, yield increase per unit area should be realized through efficient management of irrigation water. Partial root-zone and alternate furrow irrigation practice, together with organic and biofertilizers, may be applied to identify the actual water requirements and water productivity of maize under a full, alternate, and fixed partial root-zone irrigation system in a water-deficient environment. At the same time, an analysis may be conducted of the interaction of biofertilization with organic fertilization on maize yield and water productivity.

MATERIALS AND METHODS

A field experiment was conducted in the Yusufiyah region, Baghdad Governorate, to cultivate maize (*Zea mays* L.) during the fall agricultural season of 2022. The field soil was classified as Typic Torrifluvent, characterized as alluvial with a silt loam texture. The experimental site had a flat topography, with an electrical conductivity (EC) of 2.21 dS m^{-1}, a soil pH of 7.61, and soil particle 255, 493, and 252 g kg^{-1} for sand, silt, and clay, respectively. The organic matter and carbonate mineral content were 8.2 g kg^{-1} and 235 g kg^{-1}, respectively. In contrast, the available water content in the soil was 0.188 cm^3 cm^{-3}, and the bulk density was 1.32 Mg m-3 as determined by the methods. The experiment was conducted using a randomized complete block design (RCBD) in a split-plot arrangement with three replications. The main plots included different irrigation treatments as follows:

1. Conventional furrow irrigation (I1): Furrows were irrigated based on a 55% depletion of available water, with water added to field capacity for all furrows in each irrigation.
2. Alternate partial root-zone irrigation (I2): Furrows were irrigated alternately, meaning that in one irrigation, certain furrows received water, while in the

subsequent irrigation, water application was shifted to the previous dry furrows. This alternation continued throughout the growing season.

3. Fixed partial root-zone irrigation (I3): Only the first and third furrows were irrigated consistently throughout the growing season, while the others remained dry.

The subplots involved different fertilization treatments, as follows:

1. Full mineral NPK fertilization (T1): The recommended maize fertilization rate of 200 kg N ha^{-1} (urea 46% N), 78.5 kg P ha^{-1} (DAP 18% N, 23.3% P), and 120 kg K ha^{-1} (potassium sulfate 41.5% K) was applied. DAP and potassium sulfate were incorporated at sowing, while urea was applied in two doses: the first at 25 days after sowing (DAS) and the second at 60 DAS (flowering stage).
2. %50mineral fertilizer + biofertilizer (T2): Biofertilizer containing nitrogen-fixing bacteria (Azotobacter chroococcum) and phosphate-solubilizing bacteria (Pseudomonas fluorescens) was applied via seed inoculation.
3. %50mineral fertilizer + organic fertilizer (T3): ORGEVIT, a poultry manure-derived organic fertilizer, was applied at 2000 kg ha^{-1}. It contained total nitrogen (4%), organic nitrogen (3.6%), total phosphorus (3%), and total potassium (%2.5).
4. %50 mineral fertilizer +biofertilizer (T2) + organic fertilizer (T3) provides (T4): This treatment combined biofertilizer (T2) and organic fertilizer (T3).

Following land preparation (plowing, leveling, and smoothing), the field was divided into experimental units (4 m × 6 m), with six furrows per plot, each 6 m long and spaced 75 cm apart. A buffer zone of 1.5 m between plots and 2 m between replications was maintained to prevent nutrient movement between treatments. Maize seeds (Fajr variety, a local hybrid) were sown on July 25, 2022, and the crop was harvested on November 20, 2022, after reaching physiological maturity. Yield components and other agronomic traits were evaluated, and data were statistically analyzed using GenStat software, with treatment means compared using the least significant difference (LSD) test at the 5% probability level. The furrow irrigation system was calibrated by testing three operating pressures (100, 200, and 300 kPa) to determine the most efficient pressure based on irrigation efficiency, uniformity, and application effectiveness. The optimal operating pressure was determined to be 200 kPa. The applied water depth was calculated using Equation (1).

$$d = (\theta\_fc - \theta\_(w)) \times D \qquad (1)$$

Where:

d = Applied water depth (mm), θfc = Volumetric moisture content at field capacity ($cm^3\ cm^{-3}$)

θw = Volumetric moisture content before irrigation ($cm^3\ cm^{-3}$), D = Soil depth, equivalent to the effective root zone depth (mm)

The irrigation applications were scheduled based on crop growth stages and soil moisture depletion. Irrigations (1+2+3) were applied to a depth of 20 cm during 0–7 days (germination stage), while irrigations (4+5+6) were applied to a depth of 30 cm during 7–25 days (germination and vegetative growth stage). During the vegetative growth stage (25–50 days), irrigations (7+8+9) were applied to a depth of 40 cm. In the flowering stage (50–69 days), irrigations (10+11) were applied to a depth of 50 cm, while during the flowering and yield formation stage (69–90 days), irrigations (12+13+14) were applied to a depth of 50 cm. Irrigation was performed when 50% of the available water was depleted, replenishing moisture to field capacity while considering a furrow irrigation efficiency of 75%. Soil moisture content was determined by drying soil samples in a Kenwood Microwave Oven (Model MW940).

Figure (1): Some images illustrate the implementation of the experiment.

Water consumptive use is determined according to the water balance equation (Allen *et al*., 1998). Grain yield (kg ha^{-1}) was determined by harvesting 10 plants from the two central furrows of each experimental unit at the physiological maturity stage. The ears were separated from the vegetative parts and air-dried before shelling. The dry grain weight was then adjusted to a moisture content of 15.5%, and total yield was estimated according to the method described by Sahookie (1990). Water productivity (kg m^{-3}) was calculated based on Field Water Use Efficiency (FWUE) using Equation (2).

$$WUE\_f = Yield/Waterapplied \qquad (2)$$

Where:
WUEf = Field Water Use Efficiency (kg m^{-3})
Yield = Total grain yield (kg ha^{-1})
Water applied = Applied irrigation water (m^3 ha^{-1}).

RESULTS AND DISCUSSION

The results presented in Tables (1, 2, and 3) illustrate the components of the water balance equation for the conventional, alternate, and fixed furrow irrigation treatments, as well as for the biofertilizer and organic fertilization treatments. The values of actual evapotranspiration (ETa) varied according to the irrigation treatments, with the highest seasonal water consumption observed in the conventional furrow irrigation (I1T1) without biofertilizer and organic fertilization, reaching 623 mm per season, with a total of 15 irrigation times. In contrast, alternate furrow irrigation, without biofertilizer and organic fertilization, recorded 442 mm per season with nine events of irrigation. The fixed furrow irrigation, without biofertilizer and organic fertilization, recorded 510 mm season-1 with a total of 9 irrigation times.

The results in Tables (1, 2, and 3) show that the alternate and fixed furrow irrigation treatments applied less water depth and, inversely, significantly less seasonal water consumption both with and without the incorporation of biofertilizer plus organic fertilizer. The organic and biofertilizer + 50% mineral fertilization treatment under alternate furrow irrigation achieved the lowest seasonal water consumption of 275 mm, followed by the organic fertilizer + 50% mineral fertilization treatment under alternate furrow irrigation, which recorded 310 mm per season. Similarly, under fixed furrow irrigation, the organic and biofertilizer + 50% mineral fertilization treatment resulted in the lowest seasonal water consumption of 365 mm, followed by the organic fertilizer + 50% mineral fertilization treatment, which recorded 415 mm season-1.

The reduction in seasonal water consumption of maize in the alternate and fixed furrow irrigation treatments compared to the conventional furrow irrigation treatment can be attributed to the reduction in wetted surface area, which minimized evaporation and deep percolation losses. Additionally, the water stress induced by lower soil moisture in the dry root-zone section triggered physiological signaling from the roots experiencing moisture deficit. These signals, influenced by the interplay of abscisic acid (ABA), cytokinins, and ethylene, are transmitted through the stem to the leaves, leading to partial stomatal closure and reduced transpiration. Meanwhile, the well-irrigated root-zone maintains continuous water absorption to meet the plant's water requirements for vegetative growth, compensating for the moisture deficit in the dry root-zone. This irrigation alternation between wet and dry root zones influences soil moisture storage, which was lower in the alternate and fixed furrow irrigation treatments than in the conventional furrow irrigation treatment, as shown in Tables 1, 2, and 3.

Table (1): Water Balance Equation Components for Maize Irrigation Under Conventional Furrow Irrigation

Irrigation Treatments	I_1T_1	I_1T_2	I_1T_3	I_1T_4
Number of Irrigations	15	15	15	15
Applied Water Depth (mm/season)	601	563	498	446
Rainfall Depth (mm)	22	22	22	22
Contribution Groundwater (mm)	0	0	0	0
Drainage Depth (mm)	0	0	0	0
Actual Water Consumption (mm/season)	623	585	520	468

The higher cumulative ETa in the conventional furrow irrigation treatment was associated with greater applied water depth and a higher number of total 15 irrigation times (Table 1). This led to an increase in soil moisture content, which, in turn, affected soil structural properties due to repeated wetting and drying cycles during the growing season. These cycles may have caused rearrangement of soil particles, leading to changes in soil porosity and pore-size distribution. In contrast, the lower ETa in the alternate and fixed furrow irrigation treatments was due to the partial root-zone irrigation strategy, which reduced applied water depth and the number of irrigations, thereby decreasing both soil surface evaporation (by reducing the wet area) and plant transpiration (as a portion of the root system was exposed to dry conditions). Several studies have reported that water consumption decreases with higher moisture depletion levels and the addition of organic matter.

Table (2): Water Balance Equation Components for Maize Irrigation Under Alternate Furrow Irrigation

Irrigation Treatments	I_2T_1	I_2T_2	I_2T_3	I_2T_4
Number of Irrigations	9	9	9	9
Applied Water Depth (mm/season)	420	378	288	253
Rainfall Depth (mm)	22	22	22	22
Contribution Groundwater (mm)	0	0	0	0
Drainage Depth (mm)	0	0	0	0
Actual Water Consumption (mm/season)	442	400	310	275

Table (3): Water Balance Equation Components for Maize Irrigation Under Fixed Furrow Irrigation

Irrigation Treatments	I_3T_1	I_3T_2	I_3T_3	I_3T_4
Number of Irrigations	9	9	9	9
Applied Water Depth (mm/season)	488	463	393	343
Rainfall Depth (mm)	22	22	22	22
Contribution Groundwater (mm)	0	0	0	0
Drainage Depth (mm)	0	0	0	0
Actual Water Consumption (mm/season)	510	485	415	365

The results presented in Table 4 illustrate the impact of different irrigation and fertilization treatments on the total grain yield of maize. The average grain yield was 9.24, 9.88, and 8.45 Mg ha^{-1} for conventional furrow irrigation, alternate furrow irrigation, and fixed furrow irrigation, respectively. Statistical analysis revealed significant differences among fertilization treatments T1, T2, T3, and T4, with average yields of 7.29, 8.81, 9.79, and 10.88 Mg ha^{-1}, respectively. The highest maize grain yield was observed in the I2T4 treatment, reaching 11.76 Mg ha^{-1}, while the lowest yield was recorded in the I3T1 treatment, at 6.55 Mg ha^{-1}. The results did not indicate that there was water stress in plants due to their ability to extract water from adjacent furrows, such that neither yield nor its components were adversely affected. Indeed, fixed partial root-zone irrigation (I3) manifested no sharp reduction in yield compared to conventional furrow irrigation (I1). The difference is statistically significant, but even then, the treatment is still able to come up with a good grain yield, therefore supporting findings of earlier studies (Ati and Dawod, 2024). Nutrient uptake under partial root-zone drying was higher as compared with full irrigation systems in most crops. This is because newly developed roots under partial drying conditions actively participated in the process of water and nutrient uptake. More water went through the moist half of the half-root systems than through the full root systems. Hydraulic conductivity over the root system also increased after wetting cycles following drying periods. It was previously mentioned, these being supposedly due to reactivated developing roots actively contributing to water and nutrient uptake (Al-Obady *et al*., 2022; Ibrahim *et al*., 2023; Al-Zebary *et al*., 2023; Abdullah *et al*., 2023).

The Azotobacter bacteria play another very important role in atmospheric nitrogen fixation, something related to the enhancement of the development of the root system and its nutrient absorption, because their capacity for enzyme production is too high to regulate growth, such as gibberellic acid, indole acetic acid, and acetic acid. All these compounds play an important role in the formation of a denser root system. Pseudomonas bacteria increase available phosphorus in soils due to the solubilization of phosphate. Organic acid and oxo-chelating acid production from sugar by these bacteria in the rhizosphere leads to insoluble phosphate dissolution (Singh *et al*., 2022). Pseudomonas might also solubilize salts, particularly chlorides, and increase copper, phosphorus, and MBC availability, increasing total nitrogen concentration in the soil with sodium, magnesium, and potassium contents. Study results indicated that the enzyme activity of β-glucosidase accounted for enzymic degradation of organic matter, as the β-glucosidase enhances organic residue breakdown (Valadbeigi *et al*., 2023).

The application of Pseudomonas fluorescens led to increased fruit size and weight, with a 40% increase in root dry weight and a 17% increase in shoot biomass, when plants were inoculated with these bacteria. Pseudomonas fluorescens further lead to higher crop productivity through several mechanisms, including mobility of nutrients and plant protection, which makes biofertilizers sustainable alternatives for improving the quality of yields without increasing chemical fertilizing input (Zhuo *et al*., 2022; Zayed *et al*., 2023; Almayyahi and Al-Atab, 2024). Thus, it can effectively be said that the results of this study, in respect of the fact that the organic and biofertilizers provided essential nutrients to the maize plant regarding the NPK ratio could be good potential agents of the substitution of mineral fertilizers, especially when it involves reducing the rate at which the mineral fertilizer is applied to just 50% of the recommended rate.

Table (4): Effect of Irrigation and Fertilization Treatments on Maize Grain Yield (Mg ha^{-1})

Irrigation Treatments	Fertilization Treatments				Mean
	T_1	T_2	T_3	T_4	
I_1	7.56	8.87	9.66	10.88	9.24
I_2	7.76	9.45	10.55	11.76	9.88
I_3	6.55	8.11	9.15	10.00	8.45
LSD (0.05)	0.71				0.66
Mean	7.29	8.81	9.79	10.88	
LSD (0.05)	0.35				

Table (5) illustrates the effect of different irrigation and fertilization treatments on water productivity (field water use efficiency). The average water productivity was 1.73, 2.95, and 1.97 kg m^{-3} for conventional furrow irrigation, alternate furrow irrigation, and fixed furrow irrigation, respectively. Statistical analysis revealed significant differences in the average water productivity among fertilization treatments T1, T2, T3, and T4, which recorded 1.42, 1.85, 2.49, and 3.11 kg m^{-3}, respectively. The highest water productivity was observed in the I2T4 treatment (alternate furrow irrigation with bio + organic fertilizer), reaching 4.28 kg m^{-3}. At the same time, the lowest was recorded in I1T1 (conventional furrow irrigation with full mineral fertilization), at 1.21 kg m^{-3}.

Statistical analysis indicated significant differences in field water use efficiency across all alternate and fixed furrow irrigation treatments compared to conventional furrow irrigation. The reduced field water use efficiency in the conventional furrow irrigation treatment was attributed to the higher volume of applied irrigation water, along with increased leaching of nutrients below the root zone, leading to lower nutrient concentrations and, consequently, reduced productivity, which in turn resulted in lower water use efficiency. Conversely, higher field water use efficiency in the organic and biofertilization treatments was due to their ability to reduce nutrient leaching and enhance nutrient utilization efficiency. Additionally, the organic matter content in these treatments provided essential nutrients that contributed to increased seed production and improved soil physical properties compared to treatments without organic amendments. The application of partial root-zone irrigation was found to enhance nitrogen mineralization, though the underlying mechanisms behind this effect remain unclear. This process was accompanied by intensive microbial activity, and it was observed that partial root-zone wetting in alternate irrigation treatments could release organic nitrogen more effectively than deficit irrigation, due to microbial metabolism.

Table (5): Effect of Irrigation and Fertilization Treatments on Water Productivity (kg m^{-3})

Irrigation Treatments	Fertilization Treatments				Mean
	T_1	T_2	T_3	T_4	
I_1	1.21	1.52	1.86	2.32	1.73
I_2	1.76	2.36	3.40	4.28	2.95
I_3	1.28	1.67	2.20	2.74	1.97
LSD (0.05)	0.46				0.13
Mean	1.42	1.85	2.49	3.11	
LSD (0.05)	0.21				

CONCLUSIONS

- The fixed-rotation irrigation method was significantly more effective in saving the amount of irrigation water applied compared to conventional irrigation (irrigating all the fields simultaneously).
- The addition of organic and biofertilizers significantly increased maize yield and water productivity with half the amount of mineral fertilizer applied.
- These findings demonstrate the effectiveness of alternate partial root-zone irrigation combined with organic and biofertilizers in enhancing water productivity and improving maize yield while minimizing overall water consumption.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

دور إدارة ري المروز الجزئي والأسمدة العضوية والحيوية في الاستهلاك المائي للذرة الصفراء تحت شحة المياه

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الخلاصة

أُجريت تجربة حقلية في منطقة اليوسفية بمحافظة بغداد لزراعة الذرة خلال الموسم الزراعي الخريفي لعام 2022. صُممت الدراسة باستخدام تصميم القطاعات الكاملة العشوائية، بترتيب الالواح المنشقة بثلاث مكررات. تضمنت القطاع الرئيسي معاملات ري مختلفة: الري المروز التقليدي، الري الجزئي المتناوب لمنطقة الجذور، الري الجزئي الثابت لمنطقة الجذور. أما القطاع الثانوي، شمل معاملات تسميد مختلفة: سماد NPK المعدني المُضاف وفقًا للتوصية السمادية، 50% سماد معدني مُضاف إليه سماد حيوي (Azotobacter chroococcum كبكتيريا مثبتة للنيتروجين وPseudomonas fluorescens كبكتيريا مُذيبة للفوسفات)، 50% سماد معدني مُضاف إليه سماد عضوي طبيعي (Orgevit)، و50% سماد معدني مُضاف إليه كل من السماد الحيوي والسماد العضوي. أعطت معاملة التسميد العضوي والحيوي + 50% من التسميد المعدني مع الري بالتناوب أقل استهلاك للمياه، بلغ 275 مم/موسم، تلتها معاملة التسميد العضوي + 50% من التسميد المعدني مع الري بالتناوب، والتي سجلت استهلاكًا للمياه بلغ 310 مم/موسم. وبلغت قيم إنتاجية المياه 1.73 و2.95 و1.97 كغم/م^3 للري التقليدي، والري الجزئي بالتناوب، والري الجزئي الثابت لمنطقة الجذور، على الترتيب.

الكلمات المفتاحية: ري المروز المتبادل، ري المروز الثابت، الاورجفيت، السماد الحيوي.

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