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Water Productivity Under Alternate Partial Furrow Irrigation And Organic Fertilization For Sunflower

*Nameer T. Mahdi[1], Tareq K. Masood[2]
[1](Department of Desertification Combat, College of Agriculture / University of Baghdad, Iraq)
[2](Department of Soil Science and Water Resources, College of Agriculture / University of Baghdad, Iraq)
Corresponding Author: *Nameer T. Mahdi

Abstract: *A field experiment was conducted in Al-Rasheed Township, south of Baghdad, in 2011 fall season to evaluate the water productivity under alternate partial furrow irrigation (APFI) compared to conventional furrow irrigation (CFI). The experiment included six treatments: CFI, APFI through sunflower growth stages, $APFI_i$ alternate partial furrow irrigation through growth stages except emergence stage CFI application, $APFI_v$ through growth stages except vegetative stage CFI application, $APFI_f$ through growth stages except flowering stage CFI application and $APFI_m$ through growth stages except grain maturity stage CFI application. Organic fertilizer was applied in two rates: with organic using 10 Mg ha^{-1} (OF_1) or without 0 Mg ha^{-1} (OF_0). The experiment was designed according to the complete randomized blocks design using split plots with three replicates. 50% moisture depletion of available water was assigned to determine the depth of irrigation water and irrigation date according to the plant root zone depth and water equilibrium equation was used to determine water consumption of the sunflower. Results indicated that added irrigation water and sunflower water consumption differed with different irrigation treatments where the lower added irrigation water was in APFI treatment comparing with the other. Sunflower grain yield showed no significant differences in all APFI treatments compared to CFI treatment. OF_1 achieved an increment in the yield of 5.57% compared to OF_0. The higher field water use efficiency (WUE_f), crop water use efficiency (WUE_c) and gained irrigation water occurred in APFI compared to CFI with an increment of 91, 84, and 91.34 % respectively. Significant increment in WUE_f, WUE_c and gained irrigation water occurred in OF_1 compared to OF_0 with an increment of 5, 5.23 and 4.82 % respectively. It is clear that APFI reduced irrigation water without significant draw back on the yield and increased WUE which reflected on increasing gained water unit used in production grains of sunflower. Thus, partial irrigation can save water for enlargement of planting area or growing extra crop.*
Key words: *Partial irrigation, evapotranspiration, water use efficiency, water irrigation profitability.*

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I. Introduction

Partial root-zone irrigation (PRI) is a new irrigation technique aimed at improving yield per unit applied irrigation water with respect to conventional irrigation using higher rates of irrigation, but similar gains are often achieved with conventional deficit irrigation [1,2]. The concept of partial root-zone irrigation is applied irrigation water in space and time to generate wet-dry cycles in different sections of the root system and the amount of water which was usually much less in partial root-zone irrigation than in conventionally irrigated crops [3,4]. PRI include alternate partial root-zone irrigation (APRI) where part of the root zone is irrigated while the other part is dried, and then the previously well-watered side of the root system is allowed to dry while the previously dried side is fully irrigated [5,6]. The results demonstrated that PRI induces compensatory water absorption from the wetted zone, reduces transpiration, and maintains a higher level of photosynthesis compared with conventionally managed crops receiving much water [7]. Also reduced excessive vegetative growth of crops and increased quality of fruit [8,9]. Kang et al. [10] found when the two halves of a maize root system were alternately exposed to drying and wetting, water use was reduced by 34.4–36.8 % and total biomass production was reduced by only 6-11%, as compared with well-watered plants. Alternate furrow irrigation of maize could maintain high grain yield with up to 50% reduction in irrigation amount, which resulted in higher water use efficiency [11]. Tang et al. [12] reported that alternate furrow irrigation is an effective water-saving method in arid areas and plant vegetative growth can be controlled such that cotton seed yield can be maintained with less water but higher quality fibers. Shani-Dashtgol et al. [13] compared conventional and alternate furrow irrigation for growing sugar cane in a warm arid area, and concluded that 26% of the irrigation water was saved in alternate furrow irrigation with a 10% increase in crop production compared to conventional furrow irrigation. Du et al. [14] compared conventional, fixed partial root-zone and alternate partial root-zone furrow irrigation for growing cotton using three irrigation levels. They found that alternate partial root-zone furrow irrigation highest yield for all irrigation level scenarios with higher water use efficiency. In this research, field experiments were conducted to investigate the effect of alternate partial furrow irrigation on the amount of water added in a semi arid region, the actual water consumption use, the amount of water saved and grain yields of sunflower to assessing the crop and field water use efficiency and water productivity compared to conventional furrow irrigation.

II. Materials and methods

The research was carried out on fall season of sunflower (Helianthus annuus L.) in Al-Rasheed township southern of Baghdad (latitude 33º 04' 37" N, longitude 44º 30' 30" E, altitude 34 m above sea level), Iraq, in 2011-2012. The area has semi arid conditions, with average rainfall during the growing season (109 day of the year) were 6 mm, the average temperatures were 38.7 ºC as a maximum and 22.3 ºC as a minimum. The soil of experimental site was loam texture in the 0.6 m top of the soil surface where the clay content increased from 190 gKg^{-1} at the top 0.3 m layer to 249 gKg^{-1} at a depth between 0.3 and 0.6 m. the electrical conductivity of saturated pastes ranged between 1.62 and 1.70 dS m^{-1} and the pH was about 7.26. The soil water retention curve was determined using the pressure plate extractor method. The soil hydraulic functions were described using the van Genuchten – Mualem equations [15] from which the soil water content at field capacity (FC) and permanent wilting point (PWP) were evaluated. Physical, chemical and hydraulic properties of the soil are given in Table 1.

Table 1. Physical, chemical and hydraulic properties of the soil

Parameter	Soil layer	
	0.0–0.3 m	0.3-0.6 m
Sand (g kg^{-1})	323.00	258.00
Silt (g kg^{-1})	487.00	493.00
Clay (g kg^{-1})	190.00	249.00
Texture	Loam	Loam
Bulk Density (Mg m^{-3})	1.32	1.42
Volumetric water content at 33 Kps (cm^3 cm^{-3})	0.39	0.39
Volumetric water content at 1500 Kps (cm^3 cm^{-3})	0.20	0.20
Available water (cm^3 cm^{-3})	0.19	0.19
Basic infiltration rate (cm hr^{-1})	2.50	----
Electrical Conductivity (dSm^{-1})	1.62	1.70
pH	7.19	7.32
CEC ($Cmol_c$ kg^{-1} soil)	23.43	41.79

* Properties were estimated according to methods described in [16, 17].

Furrow irrigation method was used. Irrigation water was supplied from the wells drilled in the same experimental site. Quality properties of irrigation water are given in Table 2. The water is placed in C_4S_1 class with high sodium risk, medium EC value (5.03 dS m^{-1}), and pH 7.41, Nitrate 8.6 mgl^{-1}, and Boron 2.58 mgl^{-1}. This kind of water should be applied with care due to its high EC, $\mathbf{NO_3^-}$ and B. However, sunflower can be considered as moderately tolerant crop [18]. Irrigation water was delivered to furrow in the plots by PVC pipes, 0.05 m in diameter controlled by a water meter. The pipe divided to the secondary pipes 0.02 m in diameters and was applied water to furrow in the trial plots.

Table 2. Chemical composition of irrigation water used in the experiment

Water Source	EC	pH	Na^+	K^+	Ca^{++}	Mg^{++}	NO_3^-	B	SAR	Class
	dSm^{-1}		meL^{-1}				mgL^{-1}			
Well	5.03	7.41	11.15	0.13	7.75	8.33	8.60	2.58	3.93	C_4S_1

* Properties were estimated according to methods described in [17].

The experiment included six irrigation treatments as listed in Table 3 and two treatments of organic fertilization with adding organic fertilizer OF_1, (Italpollina 10 Mgh^{-1} content 4% of each N, P_2O_5 and K_2O) and without adding organic matter OF_0. The experiment was designed according to the complete randomized blocks design using split plots with three replicates. Irrigation treatments were assigned to the main plot, organic fertilizer to sub-plots. The data were subjected to analysis of variance and significance of differences between treatments was determined by least significant difference. The experiment plot area was 18 m^2 (6.0 m ×3.0 m); distance between furrow 0.75 m; distance between plants within furrow 0.30 m; plant density was about 44444 plants per hectare. Sunflower seed were sown on 1 August 2011 and harvested on 1 November 2011. Cultural practice like fertilization was carried out according to the Ministry of Agriculture guide in Iraq. Fertilizer applications were 200 kg N, 80 kg P and 100 kg K ha^{-1}. Dry matter, grain yield, and stem yield, oil percentage and oil yield were recorded. The crop phonological cycle was divided into four critical growth stages in view of their response to irrigation, i.e., emergence (i), vegetative (v), flowering (f), and grain maturity (m) for determination of irrigation scheduling [19].

Table 3. The irrigation treatments and description

Treatments	Description
CFI	Conventional furrow irrigation through all growing periods
APFI	Alternate partial furrow irrigation through all growing periods
$APFI_i$	alternate partial furrow irrigation through most growth stages except emergence stage where CFI was implemented
$APFI_v$	alternate partial furrow irrigation through most growth stages except vegetative stage where CFI was implemented
$APFI_f$	alternate partial furrow irrigation through most growth stages except flowering stage where CFI was implemented
$APFI_m$	alternate partial furrow irrigation through most growth stages except grain maturity stage where CFI was implemented

Soil water contents of plant root depth were determined by gravimetric method before irrigation water application and monitored gravimetrically in 0.3 m depth during emergence and vegetative stages. The depth increment to 0.6 m during flowering and grain maturity stages. Irrigation was resumed when plant-available water was depleted to 50% of that achieved in last irrigation.
Crop evapotranspiration was estimated using the following from of the water balance equation:

$$\boldsymbol{ET = I + P \pm \Delta S - R - D} \qquad (1)$$

Where ET is evapotranspiration (mm), I is the irrigation water (mm), P is the precipitation (mm), ΔS is the change in soil water storage (mm), R is the runoff, and D is the drainage below the root zone. In the equation R eliminated by blocking the end of furrows and D assumed to be negligible so that only estimated water was applied to 0.6 m soil profile to reach field capacity. Irrigation water productivity was evaluated for all treatments. Field water use efficiencies (WUE_f), crop water use efficiencies (WUE_c), and water irrigation profitability (WP) are three terms used to promote the efficiency of irrigation water at the crop production level.

$$\boldsymbol{WUE_f = \frac{yield}{I}} \qquad (2)$$

Where WUE_f is the field water use efficiencies (kg ha^{-1} mm^{-1}), yield (kg ha^{-1}) and I is the applied irrigation water depth (mm).

$$\boldsymbol{WUE_c = \frac{yield}{ET}} \qquad (3)$$

Where WUE_c is the crop water use efficiencies (kg ha^{-1} mm^{-1}), ET is the actual evapotranspiration (mm).

$$\boldsymbol{WP = \frac{price.\ yield}{water\ \ applied}} \qquad (4)$$

Where WP is the water irrigation profitability (ID m^{-3}), price of seed (ID kg^{-1}) and water applied (m^3 ha^{-1}).

III. Results and discussion

3.1 Irrigation water applied and evapotranspiration

The amounts of irrigation water applied were varied according to treatments (Table 4), the highest amount of irrigation water was applied to the CFI treatment (807 mm with OF_0 and 793 mm with OF_1) while the lowest amount of irrigation water was at APFI treatment (464 mm with OF_0 and 457 mm with OF_1). The amount of water applied to other treatments ranged between 510 – 639 mm (with OF_0) and 503 – 628 mm (with OF_1). The actual evapotranspiration (ET_a) of sunflower was different for each treatment the highest ET_a values were recorded for the CFI treatment with no water stress (735 mm with OF_0 and 723 mm with OF_1) and the lowest ET_a values were recorded at APFI treatment (441 mm with OF_0 and 432 mm with OF_1). The amount of ET_a for other treatments ranged between 476 - 612 mm (with OF_0) and 472 - 602 mm (with OF_1).

Table 4. Applied irrigation water (mm), actual evapotranspiration (ET_a) (mm) and soil water storage (mm) as affected by method of irrigation and organic fertilizer application

Treatments	NO. of irrigation	Applied irrigation water (mm)		ET_a (mm)		Soil water storage (mm)	
		OF_0	OF_1	OF_0	OF_1	OF_0	OF_1
CFI	16	807	793	735	723	78	76

APFI	9	464	457	441	432	29	31
$APFI_i$	10	510	503	486	478	30	31
$APFI_v$	13	639	628	612	602	33	32
$APFI_f$	10	526	519	487	468	46	57
$APFI_m$	10	523	514	476	472	53	48

The data in Table 5 shows that grain yield decreased when irrigation water amounts decreased, but there were no significant differences in average of sunflower grain yield of different irrigation treatments. The effected of organic fertilization on grain yield shows there were significant differences in grain yield between the two organic fertilization treatments, the superiority was for OF_1 treatment which had grain yield average of 3.51 t ha^{-1} with an increment ratio up to 3.57% comparing with OF_0 which gave grain yield up to 3.39 t ha^{-1}. The superiority of OF_1 might be organic fertilization increased the nutrient elements in soil. These results agreed with [20, 21], they found significant increase in grain yield, when organic fertilization was applied. Whereas the effect of the interaction between alternative partial irrigation through growth stage with organic fertilization had no significant differences, at 0.05 levels, on sunflower grain yield.

Table 5. The effects of irrigation treatments and organic fertilizer on sunflower seed yield (t ha^{-1})

Treatments	Organic fertilizer		Average
	OF_0	OF_1	
CFI	3.27	3.58	3.42
APFI	3.76	3.78	3.77
$APFI_i$	3.30	3.39	3.35
$APFI_v$	3.32	3.41	3.37
$APFI_f$	3.36	3.44	3.40
$APFI_m$	3.35	3.49	3.42
$LSD_{(0.05)}$	N.S		N.S
Average	3.39	3.51	
$LSD_{(0.05)}$	0.07		

3.2 Field water use efficiencies

WUE_f were different depending upon the treatments and significantly change when irrigation amount changing (Table 6). WUE_f values ranged from 4.05 (CFI with OF_0), 4.51 (CFI with OF_1) to 8.11 kg ha^{-1} mm^{-1} (APFI with OF_0), 8.26 kg ha^{-1} mm^{-1} (APFI with OF_1), in average WUE_f of APFI treatment increment ratio with 91% higher than CFI treatment. There were significant differences in WUE_f values for all APFI treatments comparing with CFI treatment. APFI treatments; $APFI_i$, $APFI_v$, $APFI_f$ and $APFI_m$ gave higher increment ratios of 55, 24, 52 and 54% than CFI treatment respectively. The low WUE_f of CFI treatment was attributed to increasing added quantity of irrigation water, in addition, increasing nutrients leaching under the root zone. Previous studies showed that much water adding and more nutrients leaching caused low water use efficiency [22, 23]. There were no significant differences among $APFI_i$, $APFI_f$ and $APFI_m$, this was attributed to the added quantity of water closely be the same, but at the same time these treatments significantly exceeded $APFI_v$ treatment which received higher water quantity due to the application of conventional irrigation during vegetative growth stage. It's clear from the table 6, that adding OF_1 led to significant increment in field water use efficiency which reached 6.39 $kg.h^{-1}.mm^{-1}$ compared with OF_0 which reached 6.10 $kg.h^{-1}.mm^{-1}$ with 5% increment ratio. That was attributed to the role of organic fertilizer in supplying required nutrients for plant growth which increased grain yield as well as the role in improving some of soil physical characteristics reducing nutrients leaching and increasing both water and nutrients use efficiency. These results agreed with those by Mikkelsen [24] from where the effects of organic matter on increasing yield.

Table 6. Field water use efficiencies (kg ha^{-1} mm^{-1})

Treatments	Organic fertilizer		Average
	OF_0	OF_1	
CFI	4.05	4.51	4.28
APFI	8.11	8.26	8.19
$APFI_i$	6.47	6.75	6.61
$APFI_v$	5.20	5.43	5.32
$APFI_f$	6.37	6.62	6.50
$APFI_m$	6.40	6.79	6.60
$LSD_{(0.05)}$	0.86		0.85
Average	6.10	6.39	
$LSD_{(0.05)}$	0.12		

3.3 Crop water use efficiencies

Table 7 showed the average of WUE_c for sunflower irrigation treatments according to equation 3. The WUE_c differed with the difference of irrigation treatments. The highest WUE_c value 8.64 kg.h^{-1}.mm^{-1} was obtained from the APFI treatment and the lowest value 4.69 kg.h^{-1}.mm^{-1} from the CFI treatment. For the rest of irrigation treatments; $APFI_i$, $APFI_v$, $APFI_f$ and $APFI_m$, were 6.95, 5.55, 7.12 and 7.21 kg.h^{-1}.mm^{-1} respectively. The statistical analysis results showed significant differences of WUE_c for APFI treatment comparing with CFI treatment, except $APFI_v$ had no significant difference with CFI. Results indicate that APFI is the most important treatment for sunflower irrigation, as sunflower is more responded to irrigation water deficit without grain yield affected. It's clear that APFI increased WUE_c where the increment ratio reached 48, 18, 52, 54 and 84 % for $APFI_i$, $APFI_v$, $APFI_f$, $APFI_m$ and APFI respectively comparing with CFI treatment. The increment in WUE_c for APFI treatments was attributed to the partial irrigation led to decrease both evaporation from soil surface and transpiration from plant, thus decreasing actual water consumption of sun flower, in addition the grain yield not affected by water deficit of partial irrigation treatments which reflected on increasing WUE_c. These results had agreed with those found by [25, 26, 27], where they obtained increasing WUE_c under APFI treatment comparing with CFI treatment. Table 7 showed that the average of WUE_c of sunflower organic fertilization treatments, significantly increased in OF_1 which was up to 6.86 kg.h^{-1}.mm^{-1} with increment ratio of 5.23 % comparing with OF_0 which was 6.52 kg.h^{-1}.mm^{-1} and that was attributed to effect of adding organic fertilizer on rising water use efficiency due to increasing water storage in soil and reducing the actual water consumption, in addition organic fertilizer is a source for nutrients that contributed increasing the yield. These results agreed with those by [28].

Table 7. Crop water use efficiencies (kg ha^{-1} mm^{-1})

Treatments	Organic fertilizer		Average
	OF_0	OF_1	
CFI	4.45	4.94	4.69
APFI	8.53	8.74	8.64
$APFI_i$	6.79	7.10	6.95
$APFI_v$	5.43	5.66	5.55
$APFI_f$	6.89	7.35	7.12
$APFI_m$	7.04	7.39	7.21
$LSD_{(0.05)}$	0.92		0.91
Average	6.52	6.86	
$LSD_{(0.05)}$	0.13		

3.4 Water irrigation profitability

The effect of irrigation treatments and organic fertilizer on water profitability calculated from equation 4 adopting 700 ID kg^{-1} grain yield as a dominant local market price for the season 2011 (table 8). The average of water profitability of irrigation treatments was correlated inversely with increasing added water quantity with significant differences and reached 446.9, 855.7, 690.7, 555.3, 678.3 and 689.2 ID. m^{-3} for CFI, APFI, $APFI_i$, $APFI_v$, $APFI_f$ and $APFI_m$ treatments respectively. APFI treatment achieved higher productivity of irrigation water with significant increment 91.34 %, exceeded other treatments comparing with CFI treatment. At the same time significantly $APFI_i$, $APFI_f$ and $APFI_m$ decreased of APFI by 19.26, 20.62 and 19.42 respectively which not significantly differed among each other and significantly increased comparing with $APFI_v$ by 24.37, 22.28 and 24.12 respectively. The increment of APFI water profitability was attributed to the decrement of added water quantity in addition of increasing grain yield productivity. Adding organic fertilizer led to increasing the average of water profitability which was up to 667.9 ID. m^{-3} for OF_1 that had significant superiority comparing with OF_0 which was 637.2 ID. m^{-3} with increment ratio of 4.82 %. This might be attributed to increasing crop productivity at adding organic matter, in addition of decreasing added water quantity. The interaction among irrigation treatments and organic fertilization had no significant differences due to adding organic fertilizer had a behavior similar to that without addition.

Table 8. Water irrigation profitability (ID. m^{-3})

Treatments	Organic fertilizer		Average
	OF_0	OF_1	
CFI	423.0	470.8	446.9
APFI	847.9	863.4	855.7
$APFI_i$	676.2	705.3	690.7
$APFI_v$	543.4	567.2	555.3
$APFI_f$	666.8	691.8	679.3
$APFI_m$	669.2	709.1	689.2
$LSD_{(0.05)}$	89.77		88.36
Average	637.8	667.9	
$LSD_{(0.05)}$	12.76		

IV. Conclusion

According to this research we can draw a conclusion that alternate partial furrow irrigation reduced the quantity of applied irrigation water by 42 % and the actual water consumption decreased by 40 % with no significant effect on sunflower grain yield and that caused increasing the profitability of used irrigation water by about 91 % comparing with conventional furrow irrigation.

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