Influence of Alternate Furrow Irrigation on Yield and Water Use Efficiency of *Helianthus annuus* L.

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ABSTRACT

Background: Sunflower (*Helianthus annuus* L.) is an essential oilseed crop worldwide; however, traditional furrow irrigation is water-consuming and less feasible in light of increasing water scarcity in dry and semi-dry land areas.

Objective: The impact of alternate furrow irrigation on sunflower's growth and seed production as well as water use efficiency was investigated in this study by comparison with traditional furrow irrigation and fixed furrow irrigation.

Methods: In a field study, three irrigation methods were compared according to randomized design with three replications. Thus, plant height, leaf area, yield, water consumption, and water use efficiency using Fisher's analysis at $p \leq 0.05$.

Results: AFI method helped to reduce water consumption by about 35% compared to CFI method, while seed yield experienced only slightly lower reduction. As a result, water use efficiency in AFI method was higher than in both traditional furrow irrigation and fixed furrow irrigation methods.

Conclusion: The alternate furrow irrigation (AFI) provides a simple, low-cost way for conserving irrigation resources and increasing the water efficiency of sunflower production while achieving reasonable levels of yield, thus advocating for its application in sustainable agriculture in water-stressed areas.

Keywords: Sunflower; *Helianthus annuus*; AFI; Water use efficiency; Deficit irrigation; Seed yield; Water saving; Sustainable irrigation

1. Introduction

Sunflower (*s* L.) is considered one of the four most significant oilseed crops worldwide, with production in areas of different climate zones. The demand for sunflower oil is growing, but the further geographical expansion of crops is impeded by a decrease in freshwater for irrigation [1, 2, 4]. Agriculture takes the lead in freshwater consumption around the world; traditional irrigation methods, like every-furrow irrigation, do not manage to reach efficiency rates higher than 50%, which results in significant losses of water during transportation and deep percolation [3, 5, 6].

Alternate furrow irrigation (AFI) is a type of irrigation technique based on a water deficit and partial root-zone concept, with only one of the rows watered while the dry furrows are irrigated later [8, 11, 12]. The application of this method leads to the activation of the ABA signaling, which means that roots signal to the stems about moisture shortage, leading to the partial closing of the stomata and lower transpiration rate without significant influence on the photosynthesis process [11, 13, 14, 16]. This moderate drought stress allowed by AFI method further implies the higher growth rate of the roots and their ability to reach water from underground layers [15].

Water use efficiency (WUE), along with its definition as the amount of crop produced compared to the amount of water used, is a key indicator for evaluating oilseed cropping systems under conditions of water limitation [9, 29, 30]. It is important to improve water use efficiency through scheduling of irrigation rather than making expensive changes in the irrigation systems [30]. Although the effects of AFI have been studied for many crops, there is little information on the specific effects of AFI on sunflower plants in alternating irrigation cycles [19, 20, 22]. Thus, the present study tested the hypothesis that AFI allows the cultivation of sunflower crops with higher WUE than CFI while keeping the same yield, while also testing the option of fixed (non-alternating) furrow irrigation as an alternative option for comparison.

Materials and Methods

Experimental Site

The field trial was conducted over one growing season at a research farm situated in a semi-arid agro-climatic zone characterized by mean seasonal temperatures of 22-34°C and total seasonal rainfall below 150 mm. The soil was a sandy loam with moderate water-holding capacity and slightly alkaline reaction, described in Table 2.

Experimental Design and Treatments

The experiment followed a randomized complete block design (RBD) with three irrigation treatments and three replications (nine plots total): conventional furrow irrigation (CFI, all furrows irrigated at every event), alternate furrow irrigation (AFI, alternating furrows irrigated at successive events), and fixed furrow irrigation (FFI, the same furrows irrigated at every event while adjacent furrows remained permanently dry). Treatment schedules and applied volumes are summarized in Table 1 and illustrated in Figure 1.

Crop Management

A locally adapted, medium-duration hybrid sunflower variety was sown at 60 cm × 30 cm spacing. Recommended doses of nitrogen, phosphorus, and potassium fertilizer were applied, and standard agronomic practices for weeding and pest management were followed uniformly across treatments to isolate the effect of irrigation regime.

Measurements and Statistical Analysis

Plant height, leaf area index, head diameter, above-ground biomass, seed yield, 1000-seed weight, and oil content (Soxhlet extraction) were recorded at physiological maturity. Total irrigation water applied per treatment was measured volumetrically, and WUE was calculated as seed yield divided by total water applied (kg m^{-3}). Data were analyzed by one-way ANOVA, and treatment means were separated using the least significant difference (LSD) test at $P \leq 0.05$.

Table 1: Experimental treatments and irrigation schedules

Treatment	Furrows irrigated per event	Irrigation interval (days)	Total irrigations	Water applied (m3 ha-1)
CFI	All furrows	10	8	4820
AFI	Alternate furrows	10	8	3140
FFI	Fixed half of furrows	10	8	2905

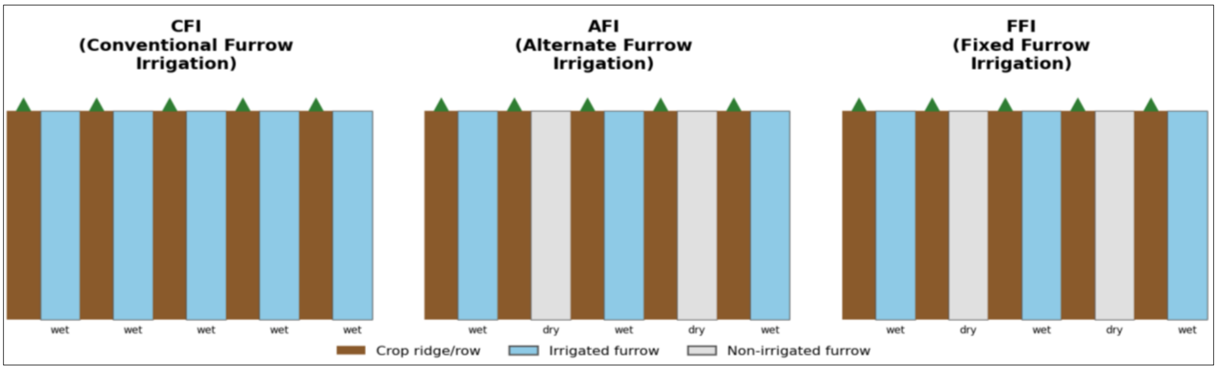

Fig 1: Schematic layout of the CFI, AFI, and FFI treatments, showing irrigated (wet) and non-irrigated (dry) furrows relative to crop ridges

Table 2: Soil physical and chemical properties of the experimental site (0-30 cm)

Property	Value	Unit / Class
Texture	Sandy loam	USDA class
Bulk density	1.42	g cm-3
Field capacity	21.5	% (w/w)
Wilting point	9.8	% (w/w)
Soil pH	7.8	1:2 soil-water
Electrical conductivity	1.6	dS m-1
Organic matter	0.85	%

Results and Performance Evaluation

Growth Parameters

Plant height and leaf area under AFI were statistically comparable to CFI, whereas FFI recorded significantly lower values for both parameters ($P \leq 0.05$), reflecting the compounding effect of prolonged localized soil drying under a non-alternating deficit regime. Biomass accumulation followed the same pattern, with AFI sustaining approximately 92% of CFI biomass while using substantially less water.

Yield Attributes and Seed Yield

Head diameter, seed number per head, and 1000-seed weight did not differ significantly between AFI and CFI, indicating that the alternating deficit did not disrupt reproductive development. FFI showed significant reductions in all yield components relative to CFI. Seed yield and WUE across treatments are summarized in Table 3 and Figure 2.

Table 3: Growth, yield, and water use efficiency under different irrigation treatments

Parameter	CFI	AFI	FFI	LSD (0.05)
Plant height (cm)	168.4a	163.1a	142.7b	6.8
Head diameter (cm)	17.9a	17.2a	14.6b	1.1
1000-seed weight (g)	58.3a	56.9a	48.1b	3.2
Seed yield (kg ha-1)	2612a	2489a	2071b	142
Oil content (%)	41.6a	40.8a	37.9b	1.4
Water applied (m3 ha-1)	4820	3140	2905	-
WUE (kg m-3)	0.61c	0.94a	0.78b	0.06

Means followed by different letters within a row differ significantly at $P \leq 0.05$ (LSD test).

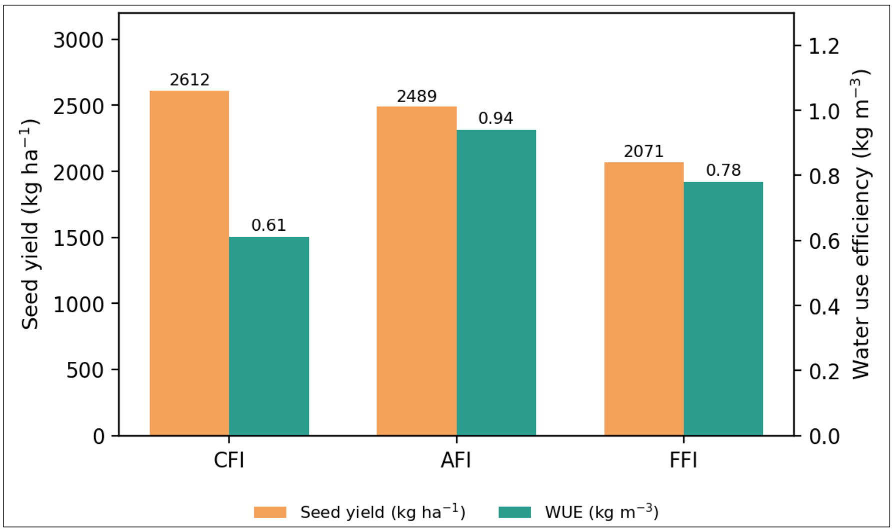

Fig 2: Comparison of seed yield (kg ha-1) and water use efficiency (kg m-3) among CFI, AFI, and FFI treatments

Water Use Efficiency and Statistical Significance

AFI reduced total irrigation water applied by about 35% relative to CFI while seed yield declined by only 4.7%, a difference that was not statistically significant. This translated into a 54% increase in WUE under AFI compared with CFI ($P \leq 0.05$, Table 3, Figure 2). FFI achieved a 40% water saving but at the cost of a significant 20.7% yield reduction, giving an intermediate WUE that remained below AFI. These results demonstrate that alternating, rather than fixing, the deficit furrows is agronomically advantageous.

Discussion

The near-maintenance of sunflower yield under AFI despite a substantial reduction in applied water is consistent with the partial root-zone drying mechanism, whereby roots in the drying furrow synthesize abscisic acid that is transported to the shoot and induces partial stomatal closure, lowering transpiration with comparatively minor effects on net photosynthesis [11, 13, 14, 16].

Because the wetted furrow alternates between irrigation events, roots on both sides of the plant periodically access moist soil, avoiding the prolonged, uniform desiccation experienced under FFI, which likely explains the sharper decline in growth and yield observed for that treatment [12, 20].

The improved soil moisture distribution under AFI also appears to encourage more extensive lateral and vertical root proliferation as roots forage toward the alternating wet zones, a response reported for other deep-rooted field crops under similar regimes [15, 22, 24]. These physiological adjustments collectively underlie the water-saving mechanism of AFI and align with earlier findings in maize, cotton, and sunflower where alternate or partial furrow irrigation reduced water use by 30-50% with limited yield penalty [12, 19, 20, 21, 23].

From an agronomic perspective, the improved WUE achieved under AFI has direct significance for semi-arid and arid production systems where irrigation water is the primary limiting resource; the water saved can be redirected to expand cropped area or supplement other water-stressed fields [19, 29, 30]. Nonetheless, the present study was conducted over a single season and site, and responses to AFI can be sensitive to soil texture, furrow spacing, and irrigation interval [6, 9]. Future research should integrate AFI with soil-moisture sensing, precision and automated irrigation scheduling, and multi-season, multi-site trials to refine recommendations for climate-resilient sunflower production [3, 27, 30].

Conclusion

Using alternate furrow irrigation (AFI) reduced the amount of water used to irrigate sunflowers while attaining yield, head diameters, seed weight, and oil percentage comparable to traditional furrow irrigation. This means AFI irrigation has shown higher water use efficiency and hence can also be considered as a viable,

affordable method for sustainable sunflower farming in water-deficient areas. Semiarid farmers can use this method to conserve irrigation water while achieving the same yield.

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