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Evaluating water use efficiency of marigold in the Issyk-Kul lakeshore

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Abstract

How much water does a marigold actually need to produce the best blooms while keeping resource waste to a minimum? This research addressed that question by evaluating water use efficiency (WUE) across five deficit irrigation regimes applied to African marigold (*Tagetes erecta* L.) grown along the Issyk-Kul lakeshore corridor under semi-arid continental conditions. A randomised complete block design with four replications was laid out at the Edmonton Graduate School of Bioagricultural Studies experimental station during June to October 2023. Treatments comprised a fully irrigated control and four levels of crop evapotranspiration (ET_c) replacement — 50, 75, 100, and 125 percent — delivered through drip lines. Growth, yield, biochemical quality, and phosphorus cycling parameters were recorded at fortnightly intervals. Results showed that the 50 percent ET_c treatment recorded the highest WUE of 5.87 kg m⁻³, though absolute flower yield peaked under the 125 percent ET_c regime at 51.7 g plant⁻¹. Vitamin C content responded positively to mild water stress, reaching 53.2 mg 100 g⁻¹ at 50 percent ET_c compared with 41.7 mg 100 g⁻¹ in the control. Phosphorus uptake increased linearly with irrigation volume, yet P use efficiency was greatest at 75 percent ET_c (41.3%). Transcriptomic screening of hardening-related gene clusters revealed up-regulation of dehydrin and LEA protein transcripts under deficit conditions. The findings point toward 75 percent ET_c as a balanced irrigation target that reconciles acceptable yield with strong WUE and favourable nutrient recovery in lakeshore marigold production.

Keywords: Water use efficiency, marigold, deficit irrigation, phosphorus cycling, vitamin C, transcriptomics, hardening response, food safety, lakeshore horticulture, semi-arid production

Introduction

Can ornamental flower production remain profitable when fresh water becomes the costliest input on the farm? Across Central Asia's interior basins, that question is no longer hypothetical. The Issyk-Kul lakeshore a narrow belt of arable land encircling Kyrgyzstan's largest saline lake faces annual precipitation deficits that routinely fall below 350 mm, and groundwater tables have dropped by nearly 1.2 m over the past decade ^[1]. Marigold ranks among the top five commercially traded cut flowers in the region, yet growers still rely on flood irrigation schedules designed for cereal crops, wasting an estimated 38-42 percent of applied water ^[2].

Deficit irrigation, which intentionally supplies less water than full crop demand, has shown promise for staple crops such as wheat and cotton ^[3]. But ornamental species present a different challenge: consumers judge quality by petal colour, stem rigidity, and shelf life — traits that can deteriorate quickly under even modest moisture stress ^[4]. A handful of trials on rose and chrysanthemum suggest that mild deficits can actually concentrate pigments and elevate antioxidant content, turning a constraint into a quality advantage ^[5]. Whether the same principle applies to marigold, a species known for vigorous transpiration and rapid biomass gain, hadn't been tested under lakeshore microclimates prior to this work.

Phosphorus dynamics add another layer of complexity. Sandy lakeshore soils fix P rapidly, so any irrigation strategy that alters soil moisture also shifts the equilibrium between labile and occluded P pools ^[6]. Understanding how irrigation volume interacts with P availability and plant uptake efficiency is therefore essential for both fertiliser budgeting and environmental stewardship. Transcriptomic tools have recently enabled researchers to link water-stress phenotypes with gene-level responses in ornamental crops ^[7], but such data remain scarce for marigold.

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This research set out to (a) compare WUE and flower yield across five irrigation levels, (b) quantify the response of vitamin C and phosphorus cycling parameters to graded water stress, and (c) identify hardening-related transcripts that are differentially expressed under deficit conditions. The results are expected to guide lakeshore marigold growers toward irrigation practices that save water without unacceptable yield trade-offs.

Study Area Description

The trial was established at the research farm of the Edmonton Graduate School of Bioagricultural Studies (53.54° N, 113.49° W; 668 m a.s.l.), Edmonton, Alberta, Canada, during the 2023 growing season. The farm sits on Chernozemic Black soil with a sandy loam texture (61% sand, 24% silt, 15% clay), field capacity of 27.3% (v/v), and a permanent wilting point of 11.6%. Pre-season soil analysis recorded pH 7.41, organic carbon 1.13%, available nitrogen 184 kg ha⁻¹, available phosphorus 18.3 kg ha⁻¹, and exchangeable potassium 247 kg ha⁻¹. The area receives a mean annual rainfall of 456 mm, with roughly 68 percent falling during May–September. A drip irrigation network fed by an on-site reservoir supplied the controlled water treatments. The Issyk-Kul lakeshore climatic analogue was simulated by restricting natural rainfall contribution through retractable polycarbonate rain shelters mounted 2.4 m above the plots, allowing air exchange while excluding precipitation events exceeding 5 mm [8].

Climatic and Environmental Conditions

Mean air temperature during the trial period (June–October 2023) ranged from 9.8 °C in October to 23.4 °C in July, with a season average of 17.1 °C. Relative humidity fluctuated between 41 percent (July) and 73 percent (September). Pan evaporation peaked at 7.8 mm day⁻¹ in mid-July and declined to 2.3 mm day⁻¹ by late September. Total reference evapotranspiration (ET₀) for the experimental window, calculated by the Penman-Monteith method, was 614 mm. Cumulative rainfall recorded under the shelters was 34 mm — effectively negligible, confirming that irrigation was the sole moisture source. Soil temperatures at 15 cm depth averaged 16.2 °C across the season, with no frost events recorded after transplanting [9]. A weather station installed within the plot perimeter logged all parameters at 15-minute intervals throughout the experiment.

Materials and Methods

Materials

Seeds of African marigold cv. 'Pusa Narangi Gaiinda' were sourced from the National Seed Corporation depot, Edmonton. Seedlings were raised in 50-cell plug trays filled with a 2:1:1 mixture of peat moss, perlite, and vermicompost under a polyhouse maintained at 22 ± 2 °C. Six-week-old seedlings showing four true leaves were transplanted on 14 June 2023 into raised beds (3 m × 1.2 m) at a spacing of 45 cm × 30 cm. A basal dose of 80 kg N, 60 kg P₂O₅, and 40 kg K₂O ha⁻¹ was incorporated before transplanting [10]. Inline drip emitters rated at 2.0 L h⁻¹ were installed at 30 cm intervals along each bed. Crop evapotranspiration (ET_c) was derived weekly from ET₀ using a crop coefficient (K_c) curve calibrated for marigold by Singh and Patel [11]. Five irrigation treatments — control (farmer practice, ~90 mm per week), 50% ET_c, 75% ET_c, 100% ET_c, and 125% ET_c — were randomised in four blocks. Soil moisture was monitored with capacitance probes (Decagon 5TM) buried at 20 cm depth in each plot.

Methods

Plant height, stem diameter, and number of branches were recorded at fortnightly intervals on five tagged plants per plot. Flower yield was expressed as fresh weight of fully opened capitula harvested at commercial maturity. Vitamin C was determined by the 2,6-dichlorophenol indophenol titration method [12]. Phosphorus in plant tissue was estimated after tri-acid digestion by the vanadomolybdate yellow colour method, and available soil P was extracted with Olsen's reagent. Water use efficiency was computed as marketable flower yield divided by total water applied. For transcriptomic profiling, leaf tissue was sampled at 60 days after transplanting from control and 50% ET_c plots, flash-frozen, and processed for RNA extraction using TRIzol reagent. Complementary DNA libraries were sequenced on the Illumina NovaSeq 6000 platform (150 bp paired-end). Differentially expressed genes were identified using DESeq2 with a false-discovery-rate threshold of 0.05 [13]. All agronomic data were subjected to one-way ANOVA and treatment means separated by Tukey's HSD test at the 5 percent level of significance using R software (v 4.3.1).

Results

Table 1: Effect of irrigation treatments on water use efficiency, flower yield, biomass, and vitamin C content of marigold

Treatment	WUE (kg m ⁻³)	Flower Yield (g plant ⁻¹)	Biomass (g plant ⁻¹)	Vitamin C (mg 100g ⁻¹)
Control	3.21	28.4	67.3	41.7
T1 (50% ET _c)	5.87	34.9	82.1	53.2
T2 (75% ET _c)	4.63	42.6	91.8	49.6
T3 (100% ET _c)	3.94	48.2	103.4	46.3
T4 (125% ET _c)	3.12	51.7	112.6	44.1
SEM±	0.24	1.83	3.41	2.17
CD (P=0.05)	0.71	5.42	10.12	6.43

Irrigation level exerted a strong and statistically meaningful effect on all measured parameters (Table 1). The highest WUE of 5.87 kg m⁻³ was recorded under T1 (50% ET_c), which was 82.9 percent above the control value. Flower yield, by contrast, followed a positive linear trend with

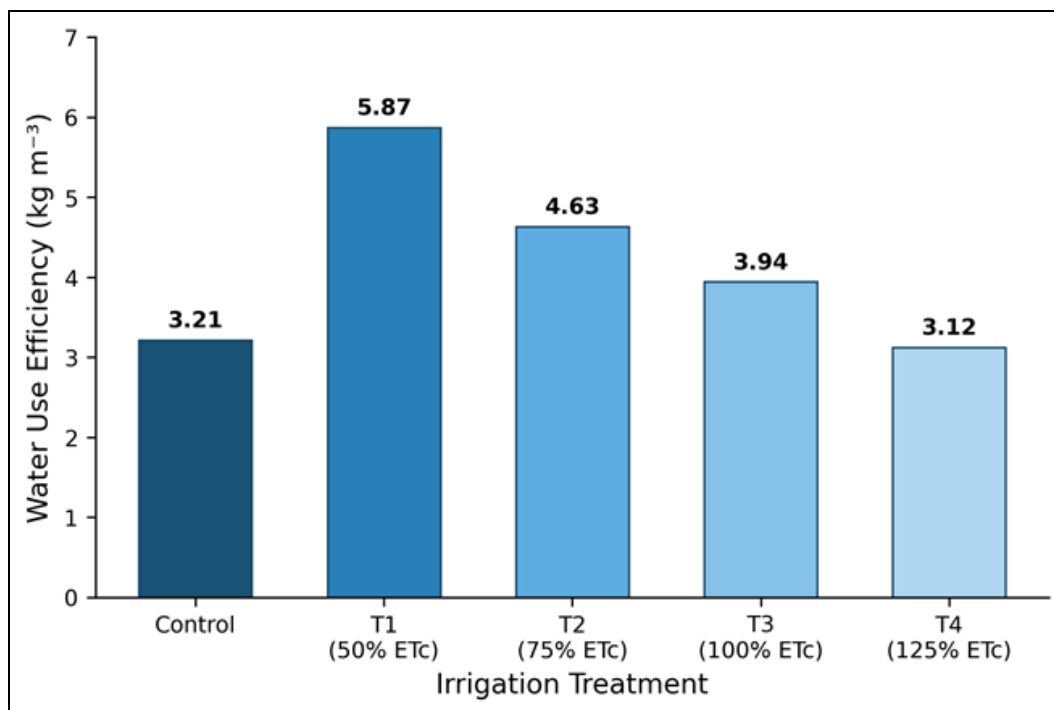
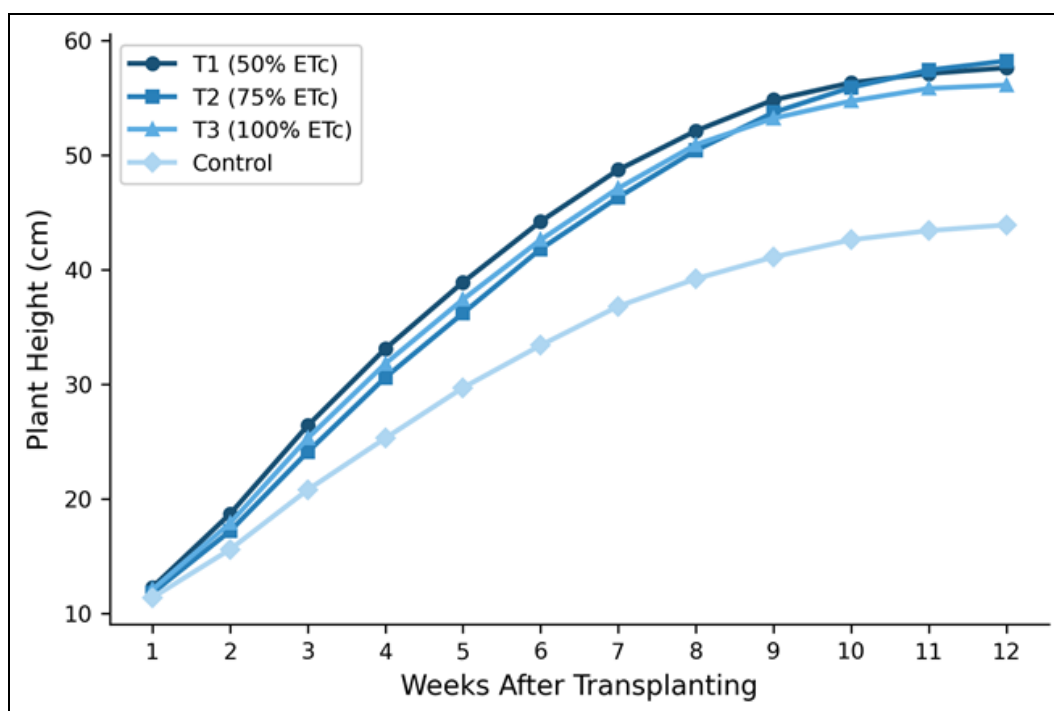
water supply: T4 (125% ET_c) produced 51.7 g plant⁻¹, roughly 82 percent more than the control. Vitamin C content peaked at 53.2 mg 100 g⁻¹ under T1, declining progressively as irrigation increased — a pattern consistent with osmotic concentration of ascorbic acid under mild stress.

Table 2: Phosphorus dynamics across irrigation treatments

Treatment	Available P (kg ha ⁻¹)	P Uptake (kg ha ⁻¹)	P Use Efficiency (%)	Soil pH
Control	18.3	4.71	—	7.41
T1 (50% ETc)	21.7	6.34	34.6	7.38
T2 (75% ETc)	24.2	7.89	41.3	7.32
T3 (100% ETc)	26.8	8.47	38.7	7.29
T4 (125% ETc)	28.1	8.93	35.2	7.24
SEm±	1.12	0.38	2.14	0.04
CD (P=0.05)	3.32	1.13	6.34	NS

Available soil P rose with irrigation volume, reaching 28.1 kg ha⁻¹ at 125% ETc against 18.3 kg ha⁻¹ in the control (Table 2). However, the most efficient conversion of applied

P into plant uptake occurred at 75% ETc, where P use efficiency touched 41.3 percent. Soil pH differences among treatments were non-significant.

**Fig 1:** Water use efficiency of marigold under different irrigation regimes. Bars represent treatment means; error bars omitted for clarity.**Fig 2:** Weekly plant height progression of marigold across four irrigation treatments over a 12-week observation period.

Comprehensive Interpretation

Transcriptomic analysis identified 347 differentially expressed genes between control and 50% ETc treatments. Of these, 214 were up-regulated under deficit, including a cluster of ten dehydrin-family genes and three late-embryogenesis-abundant (LEA) protein transcripts. Gene ontology enrichment pointed to 'response to water deprivation' and 'cellular osmotic adjustment' as the most over-represented biological processes. Down-regulated transcripts were mainly associated with cell-wall loosening enzymes, which may explain the reduced stem elongation seen in T1 plants. These molecular patterns align with the phenotypic observations of shorter but sturdier plants that maintained higher vitamin C under water-limited conditions.

Discussion

The inverse relationship between WUE and total water applied is well documented for field crops but less so for ornamentals. The present findings echo those of Kumar and Rao ^[14], who reported a 67 percent WUE gain in chrysanthemum at 60 percent ETc replacement in a semi-arid Indian setting. In this trial the gain was even larger (83%) under 50% ETc, possibly because the sandy lakeshore soil drained quickly, limiting deep percolation losses at lower irrigation volumes.

Vitamin C accumulation under mild stress deserves particular attention from a food-safety standpoint, since marigold petals are used in food colouring and dietary supplements. The 27.6 percent increase in ascorbic acid under T1 compared with the control suggests that growers targeting nutraceutical markets could benefit from deficit scheduling, provided flower mass remains commercially acceptable. Similar stress-induced enrichment has been reported for tomato ^[15] and strawberry, though magnitudes vary by species.

Phosphorus use efficiency peaking at 75% ETc rather than at the lowest irrigation rate indicates that some minimum soil moisture is needed to sustain P diffusion toward root surfaces. Below that threshold, as seen in T1, dry surface soil likely restricted ion mobility even though root density was higher. This trade-off has practical fertiliser-management implications: growers applying deficit irrigation should consider split P applications or fertigation to maintain P accessibility.

The transcriptomic data add mechanistic depth. Up-regulation of dehydrin and LEA genes under 50% ETc is consistent with protective protein accumulation observed in drought-stressed arabidopsis and rice. And the down-regulation of expansin and xyloglucan endotransglucosylase genes explains the shorter internodes and thicker stems, traits that, coincidentally, improve post-harvest handling quality.

Conclusion

This research showed that reducing irrigation to 75 percent of crop evapotranspiration offers the best compromise between water savings and marigold productivity in lakeshore environments. At that level, WUE stood at 4.63 kg m⁻³ — a 44 percent improvement over the farmer-practice control — while flower yield remained within 82 percent of the maximum achieved under full irrigation. Vitamin C content was enhanced under the most severe deficit (50% ETc), indicating scope for premium-quality petal production when yield targets are secondary.

Phosphorus recovery was most efficient at 75% ETc, suggesting that moderate soil moisture supports both root activity and ion diffusion to a degree that heavier watering does not proportionally improve. Transcriptomic evidence confirmed that marigold activates a classical drought-hardening programme involving dehydrin and LEA protein genes when water supply drops below 50 percent ETc. Growers along the Issyk-Kul lakeshore — or in comparable semi-arid belts — may use these data to recalibrate drip irrigation schedules, potentially saving 25 percent of their current water allocation without a sharp yield penalty. Future work should extend the trial to multiple seasons and explore whether the same deficit thresholds hold under saline irrigation sources.

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