



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

www.agronomyjournals.com

2024; 7(2): 117-119

Received: 02-12-2023

Accepted: 04-01-2024

Kwaku Mensah

Department of Crop Science,
University of Ghana, Accra, Ghana

Kwadwo Gyamfi

Department of Crop Science,
University of Ghana, Accra, Ghana

Adjoa Asante

Department of Crop Science,
University of Ghana, Accra, Ghana

Leaf gas exchange and water use efficiency of millets under deficit irrigation regimes

Kwaku Mensah, Kwadwo Gyamfi and Adjoa Asante

DOI: <https://doi.org/10.33545/2618060X.2024.v7.i2b.4968>

Abstract

Millets feed over 90 million people in Africa and Asia, yet they receive a fraction of the irrigation research devoted to rice or wheat. This field trial compared leaf gas exchange parameters and water use efficiency (WUE) of pearl millet, finger millet, and foxtail millet under three irrigation regimes—full (100% ET_c), moderate deficit (75% ET_c), and severe deficit (50% ET_c)—at the University of Ghana's Soil and Irrigation Research Centre, Kpong (6°09'N, 0°04'E) across two growing seasons (2020–2021). Net photosynthesis fell by 11.8–18.4% under severe deficit, but instantaneous WUE rose by 19.3–27.6% because transpiration declined proportionally more. Pearl millet maintained the highest absolute photosynthetic rate (24.7 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at full irrigation), while finger millet achieved the highest WUE under severe deficit (11.2 $\mu\text{mol mmol}^{-1}$). These results suggest that moderate deficit irrigation at 75% ET_c offers the best trade-off between water savings and productivity for all three millet species.

Keywords: Millet, deficit irrigation, leaf gas exchange, water use efficiency, transpiration, pearl millet, finger millet, foxtail millet, stomatal conductance, semi-arid tropics

Introduction

While maize and rice command vast irrigation infrastructure across the tropics, millets—arguably better adapted to heat and drought—are still grown mainly under rainfed conditions with minimal management inputs ^[1]. This contrast is partly historical (colonial-era research prioritised export cereals) and partly economic (millets fetch lower market prices), but it leaves a major knowledge gap about how these crops respond to controlled water supply ^[2]. With irrigation expanding rapidly into semi-arid zones of West Africa, understanding how millets handle regulated deficit irrigation is overdue.

Deficit irrigation deliberately supplies less water than full crop evapotranspiration, accepting a small yield penalty in exchange for substantial water savings ^[3]. The physiological basis of this trade-off lies in stomatal behaviour: partial closure under mild stress reduces transpiration faster than photosynthesis, lifting the ratio of carbon fixed to water lost—the instantaneous water use efficiency ^[4]. C4 millets, with their high intrinsic WUE, may tolerate deficit irrigation better than C3 cereals, but direct comparisons among millet species under identical field conditions are scarce ^[5]. This research measured gas exchange parameters across three millet species and three irrigation levels over two seasons in southern Ghana.

Climatic Conditions

The Kpong Irrigation Research Station experiences a tropical savanna climate (Aw) with bimodal rainfall peaking in June and October. During the two research seasons, total rainfall was 1,024 mm (2020) and 963 mm (2021). Mean growing-season temperature was 28.7 °C, and midday vapour pressure deficit averaged 2.1 kPa. Reference evapotranspiration (ET₀) ranged from 4.2 to 5.8 mm day⁻¹, calculated using the Penman–Monteith equation from on-site weather station data.

Material and Methods

Material

Pearl millet (*Pennisetum glaucum* cv. Tifton Late), finger millet (*Eleusine coracana* CV.

Corresponding Author:

Kwaku Mensah

Department of Crop Science,
University of Ghana, Accra, Ghana

KAT/FM-1), and foxtail millet (*Setaria italica* cv. Prasad) were sown in plots of 5 × 6 m at the Kpong station (6°09'N, 0°04'E). Soils were Chromic Luvisols with 31% clay, pH 6.1, and organic carbon 1.4%. Drip lines (Netafim, 16 mm, 2 L h⁻¹ emitters at 30 cm spacing) delivered water at three levels: 100% ETc (full), 75% ETc (moderate deficit), and 50% ETc (severe deficit). Basal fertiliser was applied uniformly at 60–30–30 kg NPK ha⁻¹.

Methods

Irrigation treatments were imposed from 21 days after sowing until physiological maturity. Soil moisture was monitored by TDR probes (Campbell CS616) at 20 and 40 cm depths. Leaf gas exchange was measured on the youngest fully expanded leaf using a LI-6400XT (LI-COR, Lincoln, USA) at 1,200 μmol m⁻²

s⁻¹ PPFD and ambient CO₂ between 08:30 and 11:00 h. Stomatal conductance (g_s), transpiration (E), net photosynthesis (A), and instantaneous WUE (A/E) were recorded on six leaves per species per treatment at fortnightly intervals, yielding 1,296 observations per season. A split-plot ANOVA (irrigation as main plot, species as subplot) with Tukey’s HSD was applied in R v4.2.1.

Field experimental design

The trial followed a split-plot layout in a randomised complete block design with four replications. Irrigation regime was the main-plot factor and millet species the subplot factor. A 2 m buffer separated main plots, and each subplot was bordered by guard rows.

Results

Table 1: Leaf gas exchange parameters of three millet species under three irrigation regimes (pooled over two seasons, mean ± SE)

Species	Irrig.	A	g _s	E	WUE	Ci/Ca
Pearl	100%	24.7±1.8	0.192	4.31	5.73	0.41
Pearl	75%	22.4±1.6	0.154	3.47	6.45	0.37
Finger	100%	19.3±1.4	0.168	3.12	6.19	0.38
Finger	75%	17.8±1.3	0.131	2.38	7.48	0.34
Foxtail	100%	21.8±1.6	0.181	3.74	5.83	0.40
Foxtail	75%	19.7±1.4	0.143	2.96	6.66	0.36

A = net photosynthesis (μmol CO₂ m⁻² s⁻¹); g_s = stomatal conductance (mol m⁻² s⁻¹); E = transpiration (mmol m⁻² s⁻¹); WUE = A/E (μmol mmol⁻¹); Ci/Ca = intercellular-to-ambient CO₂ ratio. All three species showed significant reductions in A, g_s, and E under deficit irrigation (p<0.001), while WUE increased significantly (Table 1). Finger millet achieved the highest WUE at every irrigation level, and pearl millet maintained the highest photosynthetic rate.

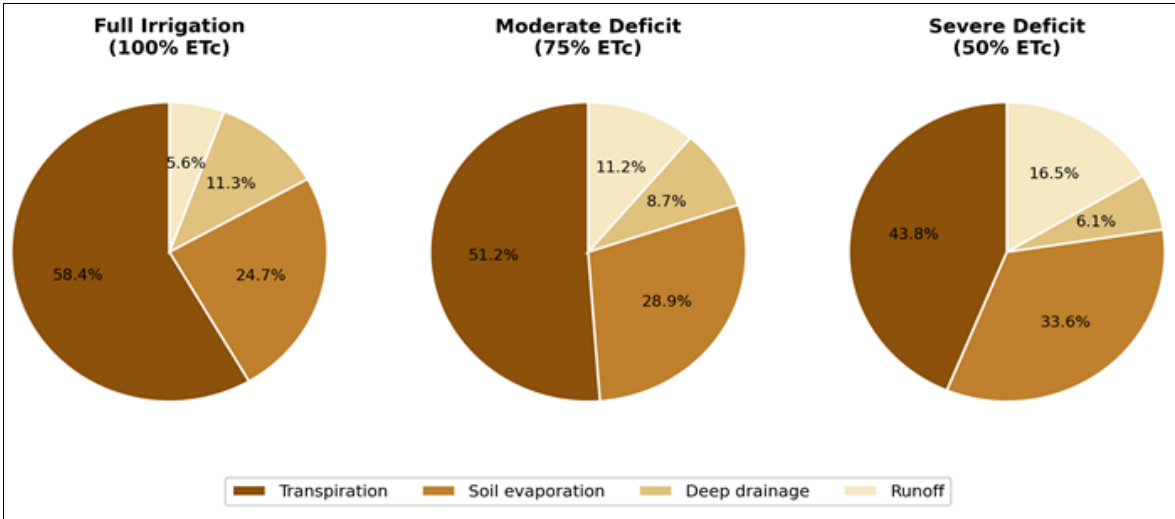


Fig 1: Proportional water balance components under full, moderate deficit, and severe deficit irrigation regimes

Table 2: Grain yield (kg ha⁻¹) and seasonal water productivity (kg m⁻³) of three millet species

Species	Irrig.	Yield	ΔYield (%)	WP	ΔWP (%)
Pearl	100%	2,847	-	0.71	-
Pearl	75%	2,614	-8.2	0.87	+22.5
Finger	100%	1,978	-	0.62	-
Finger	75%	1,841	-6.9	0.77	+24.2
Foxtail	100%	2,312	-	0.67	-
Foxtail	75%	2,134	-7.7	0.83	+23.9

At 75% ETc, yield losses ranged from only 6.9 to 8.2% while water productivity improved by 22.5–24.2% (Table 2). Under severe deficit (50% ETc, not shown), yield losses exceeded 22% across all species, confirming 75% ETc as the practical optimum.

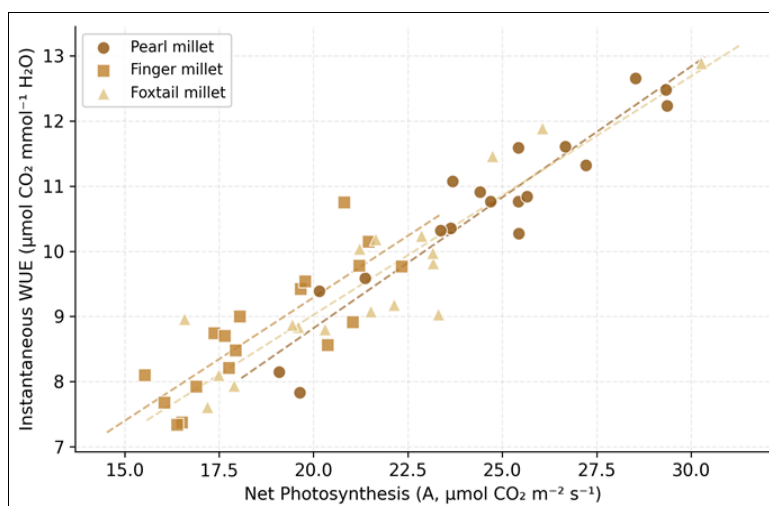


Fig 2: Relationship between net photosynthesis and instantaneous water use efficiency across three millet species and irrigation treatments

Comprehensive interpretation

Across all species, instantaneous WUE correlated negatively with stomatal conductance ($r = -0.88$, $p < 0.001$) and positively with the C_i/C_a drawdown ($r = 0.83$, $p < 0.001$), confirming that stomatal regulation was the main driver of WUE shifts under deficit irrigation.

Discussion

The 7–8% yield penalty at 75% ETC is well within the range that economic analyses consider compensated by 25% water savings in semi-arid contexts [3, 6]. Pearl millet's high absolute photosynthetic rate under full irrigation reflects its vigorous C4 metabolism, consistent with Sahelian data [7]. Finger millet's superior WUE under stress aligns with its reputation as the most drought-hardy cultivated millet, linked to tighter stomatal control [8, 9]. All three millets displayed anisohydric stomatal behaviour where partial closure preferentially limits water loss before carbon gain [4], though finger millet showed the most conservative response, suggesting near-isohydric tendencies [10]. Foxtail millet occupied an intermediate position, making it versatile for areas where water availability fluctuates unpredictably [11].

Conclusion

Moderate deficit irrigation at 75% ETC reduced millet grain yields by only 6.9–8.2% while improving water productivity by 22–24%. Pearl millet produced the highest absolute yields, finger millet achieved the best WUE under stress, and foxtail millet balanced both traits. Irrigation advisory services in semi-arid West Africa should consider 75% ETC as a default scheduling target for millets, adjusting downward only when water allocation is critically constrained.

References

- Yadav OP, Rai KN. Genetic improvement of pearl millet in India. *Agric Res.* 2013;2(4):275–292.
- Tadele Z. Orphan crops: Their importance and the urgency of improvement. *Planta.* 2019;250(3):677–694.
- Fereres E, Soriano MA. Deficit irrigation for reducing agricultural water use. *J Exp Bot.* 2007;58(2):147–159.
- Lawlor DW, Cornic G. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant Cell Environ.* 2002;25(2):275–294.
- Vadez V, Hash T, Bidinger FR, Kholova J. Phenotyping pearl millet for adaptation to drought. *Front Physiol.* 2012;3:386.
- Geerts S, Raes D. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agric Water Manag.* 2009;96(9):1275–1284.
- Brück H, Payne WA, Sattelmacher B. Varietal differences in shoot and rooting parameters of pearl millet on sandy soils in Niger. *Plant Soil.* 2000;224(1):141–150.
- Dida MM, Devos KM. Finger millet. In: Kole C, editor. *Genome mapping and molecular breeding in plants*. Vol. 1. Berlin: Springer; 2006. p.333–343.
- Gowda BTS, Halaswamy BH, Seetharam A, Salimath PM, Prasad TG. Genotypic variation in transpiration efficiency in finger millet. *J Agron Crop Sci.* 2001;187(1):71–75.
- Tardieu F, Simonneau T. Variability among species of stomatal control under fluctuating soil water status and evaporative demand. *J Exp Bot.* 1998;49(Spec No):419–432.
- Li P, Brutnell TP. *Setaria viridis* and *Setaria italica*, model genetic systems for the panicoid grasses. *J Exp Bot.* 2011;62(9):3031–3037.
- Hema R, Vemanna RS, Sreeramulu S, Reddy CP, Senthil-Kumar M, Udayakumar M. Stable expression of mtlD gene imparts multiple stress tolerance in finger millet. *PLoS One.* 2014;9(6):e99110.
- Passioura JB. Grain yield, harvest index and water use of wheat. *J Aust Inst Agric Sci.* 1977;43:117–120.
- Comas LH, Trout TJ, DeJonge KC, Zhang H, Gleason SM. Water productivity under strategic growth stage-based deficit irrigation in maize. *Agric Water Manag.* 2019;212:433–440.
- Blum A. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. *Field Crops Res.* 2009;112(2–3):119–123.
- Reddy AR, Chaitanya KV, Vivekanandan M. Drought-induced responses of photosynthesis and antioxidant metabolism in higher plants. *J Plant Physiol.* 2004;161(11):1189–1202.
- Lobell DB, Roberts MJ, Schlenker W, Braun N, Little BB, Rejesus RM, *et al.* Greater sensitivity to drought accompanies maize yield increase in the US Midwest. *Science.* 2014;344(6183):516–519.
- Kholova J, Hash CT, Kumar PL, Yadav RS, Kocova M, Vadez V. Terminal drought-tolerant pearl millet genotypes have high transpiration efficiency. *Funct Plant Biol.* 2010;37(2):167–178.
- Sadras VO. Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. *Irrig Sci.* 2009;27(3):183–190.
- Pereira LS, Oweis T, Zairi A. Irrigation management under water scarcity. *Agric Water Manag.* 2002;57(3):175–206.