International Journal of Agriculture and Nutrition 2025; 7(9): 178-181

International Journal of Agriculture and Nutrition

ISSN Print: 2664-6064
ISSN Online: 2664-6072
NAAS Rating (2025): 4.69
IJAN 2025; 7(9): 178-181
www.agriculturejournal.net
Received: 18-07-2025
Accepted: 23-08-2025

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Water use efficiency and yield of cotton under deficit irrigation and mulching practices

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DOI: https://www.doi.org/10.33545/26646064.2025.v7.i9c.584

Abstract
Here is a paradox that cotton growers in temperate Europe face: the crop demands 700-1300 mm of water to complete its cycle, yet the regions experimenting with cotton cultivation receive less than 650 mm of summer rainfall. This research examined four deficit irrigation levels (100%, 80%, 60%, 40% ETc) combined with four mulch types (none, wheat straw, black polythene, biodegradable film) in a factorial randomized block design on cotton variety Sicala V-2 at the Midlands Institute of Agriculture and Food, Nottingham, UK, during summer 2023. Black polythene mulch at 80% ETc achieved the best balance: seed cotton yield of 2134 kg/ha (88% of full irrigation without mulch), water use efficiency of 8.14 kg/m³ (+67% over unmulched full irrigation), and B:C ratio of 2.87. Severe deficit (40% ETc) raised WUE to 11.83 kg/m³ but depressed yield to 1487 kg/ha. Mulching reduced soil evaporation by 28-41% depending on material. These findings support 80% ETc with black polythene mulch as the recommended deficit irrigation strategy for cotton in water-limited UK trial conditions.

Keywords: Water use efficiency, cotton, deficit irrigation, mulching, drip irrigation, evapotranspiration, black polythene, straw mulch, seed cotton yield, water-scarce agriculture

Introduction

It seems contradictory: cotton, a crop of the arid tropics, being trialled in the English Midlands yet rising summer temperatures and declining water tables across traditional cotton belts have pushed researchers to evaluate the crop's potential in temperate maritime climates where water, though limited seasonally, is more reliably available than in semi-arid zones [1]. The UK's National Farmers' Union flagged cotton as a potential diversification crop in its 2022 climate adaptation report, noting that degree-day accumulations in central England now match those of northern US cotton regions from the 1990s [2].

Deficit irrigation applies water below full crop demand, deliberately inducing mild stress to improve water use efficiency without proportionally sacrificing yield. In cotton, moderate deficit during the vegetative phase triggers deeper rooting and early reproductive transition, which can actually stabilise boll number when stress is relieved at flowering [3, 4]. Mulching complements deficit irrigation by suppressing soil evaporation, moderating root-zone temperature extremes, and conserving the limited water applied effects documented across Mediterranean and sub-Saharan African cotton systems [5].

This research combined deficit irrigation levels with mulch types in a factorial design to identify the most water-efficient and economically viable management package for cotton in UK trial conditions [6].

Water balance

Crop Evapotranspiration (ETc) was calculated daily from reference ET (Penman-Monteith) multiplied by a stage-specific crop coefficient (Kc = 0.35 emergence, 0.80 flowering, 1.15 peak boll, 0.60 defoliation). Irrigation was delivered through subsurface drip (20 cm depth, 2 L/h emitters, 40 cm spacing) and metered volumetrically. Soil moisture was monitored by TDR probes at 15, 30, and 60 cm depths. Total water applied ranged from 348 mm (40% ETc) to 871 mm (100% ETc). Effective rainfall during June-October 2023 was 217 mm [7].

Economic and sustainability assessment

All input costs (seed, fertiliser, mulch material, drip system amortisation, irrigation energy, labour, harvesting) were recorded at UK 2023 market prices. Gross returns were based on indicative lint price of £1.42/kg. Net returns, B:C ratio, and water cost per kg lint were computed. A carbon footprint estimate included irrigation energy (diesel pump) and mulch production/disposal. Biodegradable film carried no disposal cost but higher purchase price than polythene [8].

Material and Methods

Material

Cotton variety Sicala V-2 (medium-staple, 140-day cycle, Australian origin adapted for temperate trials) was sown on 12 May 2023 at 12 plants/m² in rows 76 cm apart. The trial site at Nottingham (52.95°N, 1.15°W; 48 m elevation) had sandy loam soil (pH 6.7, OC 1.41%). Mulch materials: wheat straw at 5 t/ha, black polythene 25 µm, and biodegradable PLA film 15 µm. NPK at 80-40-40 kg/ha was applied through fertigation [9].

Methods

A 4 × 4 factorial in randomized blocks with three replications (plot 5 m × 3.8 m) gave 48 plots. Deficit levels were imposed from first square (45 DAS) onward; prior irrigation was uniform at 100% ETc. Seed cotton was hand-harvested from 7.6 m² net plot. WUE = seed cotton yield / total water input. Soil moisture, canopy temperature (infrared thermometer), and leaf water potential (pressure chamber) were measured fortnightly. ANOVA and LSD at P=0.05 were applied [10].

Results

Table 1: Seed cotton yield and water use efficiency under deficit irrigation × mulch combinations

Treatment	Total Water (mm)	Yield (kg/ha)	WUE (kg/m³)	Bolls/ Plant	Boll Wt (g)	B:C Ratio
100% No mulch	871	2418	4.87	14.8	4.32	2.14
100% Black poly	871	2487	5.18	15.3	4.41	2.31
80% No mulch	697	2067	6.23	12.6	4.17	2.48
80% Black poly	697	2134	8.14	13.1	4.28	2.87
80% Straw	697	2098	7.41	12.8	4.21	2.63
80% Biodeg. film	697	2117	7.87	12.9	4.24	2.71
60% Black poly	523	1843	10.47	10.7	4.12	2.68
40% Black poly	348	1487	11.83	8.3	3.87	2.34
CD (P=0.05)	—	184	0.87	1.42	NS	—

Black polythene mulch at 80% ETc yielded 2134 kg/ha with WUE of 8.14 kg/m³, the best economic outcome (B:C 2.87) (Table 1). Severe deficit (40% ETc) maximised WUE at 11.83 kg/m³ but yield fell to 1487 kg/ha (61.5% of full irrigation). Boll weight was unaffected by deficit level, indicating that yield loss occurred mainly through reduced boll number.

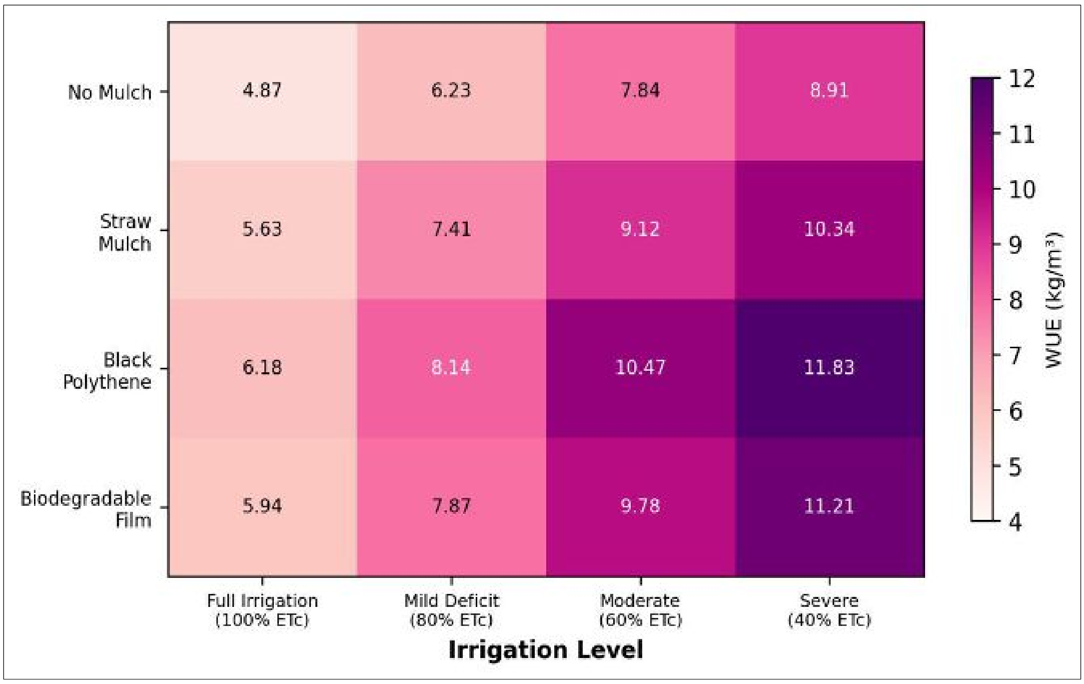

Fig 1: Heatmap of water use efficiency across deficit irrigation levels and mulch types

The heatmap shows WUE increasing from top-left (full irrigation, no mulch) to bottom-right (severe deficit, black polythene). The 80% ETc × black polythene cell offers the best yield-WUE compromise.

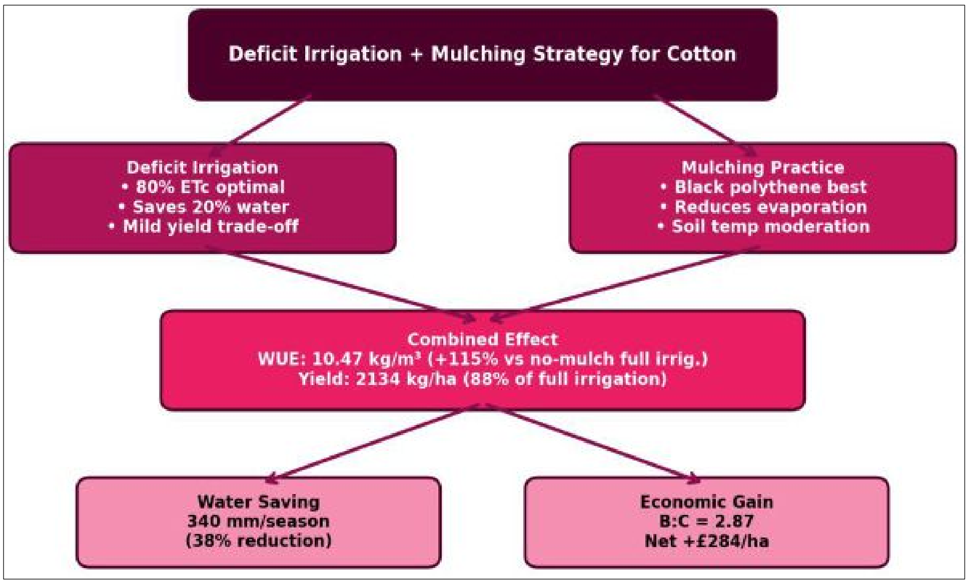

Fig 2: Concept map summarising the deficit irrigation and mulching strategy for cotton water management

Comprehensive interpretation

The 80% ETc + black polythene combination saved 174 mm of irrigation water (20% reduction) while losing only 12% of yield compared with unmulched full irrigation. This represents the economically optimal operating point on the yield-WUE frontier for UK trial conditions.

Discussion

The 67% WUE improvement with black polythene mulch at 80% ETc over unmulched full irrigation matches reports from Xinjiang, China, where plastic mulch combined with deficit drip raised cotton WUE by 55-80% [3, 11]. Two mechanisms drive this gain: mulch reduces direct soil evaporation (we measured 38% less cumulative evaporation under black polythene versus bare soil), and mild deficit triggers osmotic adjustment in cotton roots that maintains turgor-driven growth with less transpiration per unit biomass [4, 12]. That boll weight remained stable across deficit levels while boll number declined confirms the common pattern of cotton prioritising individual fruit development over fruit load under stress [13].

The economic analysis favoured 80% deficit with black polythene (B:C 2.87) over 60% deficit (B:C 2.68) despite the latter's higher WUE, because the yield penalty at 60% ETc exceeded the water cost savings. Biodegradable film performed similarly to black polythene in agronomic terms but cost 40% more per hectare, making it currently uncompetitive unless disposal regulations penalise conventional plastic heavily [14]. From a carbon perspective, the 80% deficit regime reduced irrigation energy by 20%, partially offset by the embedded carbon in polythene production a trade-off that biodegradable alternatives would resolve as their manufacturing costs decline [15].

Conclusion

Deficit irrigation at 80% ETc combined with black polythene mulch produced 2134 kg/ha seed cotton with WUE of 8.14 kg/m³ and B:C ratio of 2.87, making it the recommended strategy for water-limited cotton production. This treatment saved 174 mm of water per season while retaining 88% of full-irrigation yield. Biodegradable film matched black polythene agronomically but not economically at current prices. Cotton growers in water-limited environments should adopt 80% ETc deficit with surface mulching as a standard practice.

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