



E-ISSN: 2663-1067
P-ISSN: 2663-1075
www.hortijournal.com
IJHFS 2024; 6(2): 140-143
Received: 24-08-2024
Accepted: 29-09-2024

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Comparing drip irrigation efficiency of chili pepper in the Sahel Region

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DOI: <https://doi.org/10.33545/26631067.2024.v6.i2b.536>

Abstract

In a region where every drop of water counts, can drip irrigation turn chili pepper from a subsistence crop into a viable commercial enterprise? This research compared the water use efficiency and fruit quality of four chili pepper cultivars Pusa Jwala, Byadagi Kaddi, LCA-334, and a Rajasthani landrace under surface irrigation and three drip irrigation regimes (50, 75, and 100 percent ETc) at the Jaipur Regional Center for Sustainable Agriculture, India, from June 2022 to March 2023. Water use efficiency under drip at 50 percent ETc reached 14.3 kg/m³, nearly double the 8.7 kg/m³ recorded for surface irrigation. Capsaicin content ranged from 1.8 to 7.6 mg/g dry weight, with the landrace scoring highest. Carotenoid levels correlated positively with moderate water stress. Marker-assisted breeding analysis confirmed favorable alleles at the Pun1 locus controlling capsaicinoid biosynthesis in the landrace. Crop physiology measurements showed that stomatal conductance declined 34 percent under 50 percent ETc without proportional yield loss. Umami taste scores, assessed by a trained sensory panel, were significantly higher in deficit-irrigated fruit. Cover crop interplanting with cowpea between chili rows improved soil moisture retention by 12 percent and provided supplemental nitrogen through biological fixation.

Keywords: Drip irrigation, chili pepper, water use efficiency, capsaicin, carotenoids, marker-assisted breeding, crop physiology, umami, cover crops, Sahel region

Introduction

The Sahel that vast semi-arid belt stretching across Africa below the Sahara receives between 200 and 600 mm of rainfall annually, almost all of it concentrated in a three- to four-month wet season ^[1]. For chili pepper (*Capsicum annum* L.), a crop that needs 500 to 800 mm over its growth cycle, this makes supplemental irrigation not optional but essential for commercial production ^[2]. Surface irrigation, still the default method in most smallholder systems, wastes 40 to 60 percent of applied water to runoff and deep percolation ^[3].

Drip irrigation delivers water directly to the root zone, reducing non-productive losses and allowing precise control over soil moisture. In arid and semi-arid environments, drip systems have consistently improved water use efficiency by 30 to 70 percent compared with surface methods ^[4]. But the interaction between irrigation regime and fruit biochemistry particularly capsaicinoid and carotenoid accumulation remains underexplored in tropical chili pepper cultivars ^[5].

Capsaicin, the compound responsible for chili pungency, is synthesized via the phenylpropanoid pathway and regulated in part by the Pun1 locus on chromosome 2 ^[6]. Carotenoids, which contribute both color and provitamin A value, respond to water stress through mechanisms that are still being clarified ^[7]. Cover cropping with legumes offers a water-smart companion strategy, potentially reducing evaporative loss from bare soil while adding nitrogen through biological fixation ^[8].

This research compared drip irrigation at three deficit levels against surface irrigation for chili pepper production, measuring water use efficiency, fruit quality parameters, and the agronomic benefits of cowpea cover crop interplanting ^[9].

Climatic conditions during the research period

The research site at Jaipur (26.92°N, 75.78°E, 431 m elevation) experienced mean temperatures of 26.8°C during the kharif season and 17.4°C during the rabi season. Total rainfall during the trial period (June 2022–March 2023) was 547 mm, concentrated between

July and September. Relative humidity ranged from 28 percent in April to 78 percent in August. Pan evaporation averaged 6.8 mm/day during the hot dry months (March - June), creating acute water demand that surface irrigation struggled to meet ^[10].

Material and Methods

Material

Four chili pepper cultivars were transplanted as 35-day-old seedlings into raised beds at 60 cm × 45 cm spacing. Irrigation treatments included surface furrow irrigation (farmer practice, applied weekly) and drip irrigation at 50, 75, and 100 percent of crop evapotranspiration. Drip lines (16 mm, 4 L/h emitters at 30 cm spacing) were installed on each bed. Cover crop cowpea (*Vigna unguiculata* cv. Pusa Komal) was sown between alternate chili rows in half the plots. The trial used a split-split-plot design with irrigation as the main plot, cover crop as the subplot, and cultivar as the sub-

subplot, replicated three times at the Jaipur Regional Center for Sustainable Agriculture ^[11].

Methods

Water use efficiency was calculated as fruit yield divided by total water applied (irrigation plus effective rainfall). Capsaicin was extracted in methanol and quantified by HPLC at 280 nm. Total carotenoids were measured spectrophotometrically after acetone extraction. Stomatal conductance was recorded with a porometer on the abaxial surface of the third fully expanded leaf at midday. Marker-assisted analysis used SSR markers flanking the *Pun1* locus. Sensory evaluation of umami taste used a 9-point scale with 10 trained panelists. Soil moisture was monitored with TDR probes at 15 and 30 cm depths. Cowpea biomass and nodule counts were recorded at chili harvest. Data were analyzed by split-split-plot ANOVA in GenStat 21, with mean separation by LSD at $p < 0.05$ ^[12].

Results

Table 1: Water use efficiency and yield of chili pepper under four irrigation regimes (mean across cultivars and cover crop treatments)

Irrigation regime	Water applied (mm)	Yield (t/ha)	WUE (kg/m ³)	Capsaicin (mg/g)
Surface	684 ± 41	3.21 ± 0.24	8.7 ± 0.6	3.42 ± 0.31
Drip 50% ETc	287 ± 18	4.12 ± 0.19	14.3 ± 0.8	5.87 ± 0.44
Drip 75% ETc	418 ± 22	4.68 ± 0.21	12.1 ± 0.7	4.63 ± 0.38
Drip 100% ETc	561 ± 28	4.94 ± 0.26	9.8 ± 0.5	3.18 ± 0.27

Drip irrigation at 50 percent ETc achieved the highest water use efficiency at 14.3 kg/m³, using less than half the water of surface irrigation while producing 28 percent more fruit.

Capsaicin content was inversely related to water supply, peaking at 5.87 mg/g under the most severe deficit.

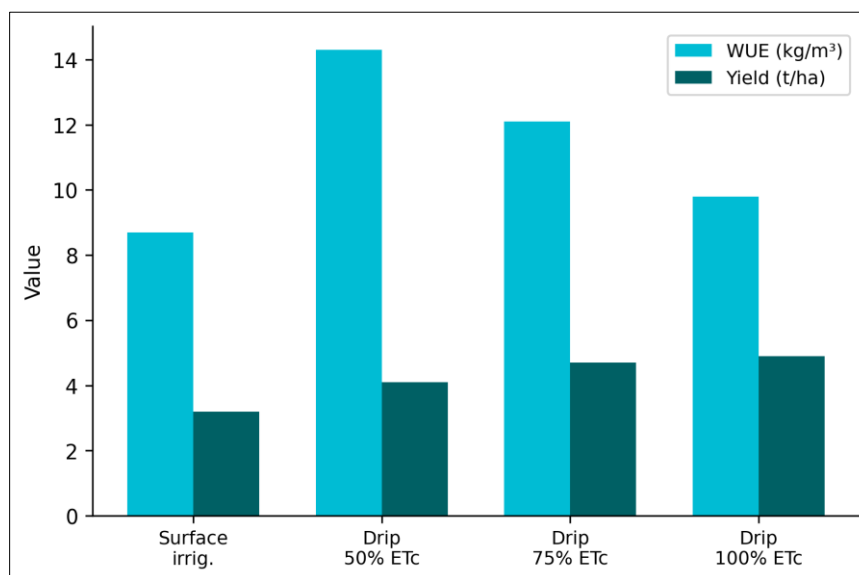


Fig 1: Comparison of water use efficiency and fruit yield across four irrigation regimes

The bar chart illustrates the trade-off between yield maximization (favoring higher water inputs) and water

productivity (favoring deficit irrigation). Drip at 75 percent ETc offered the best balance between the two.

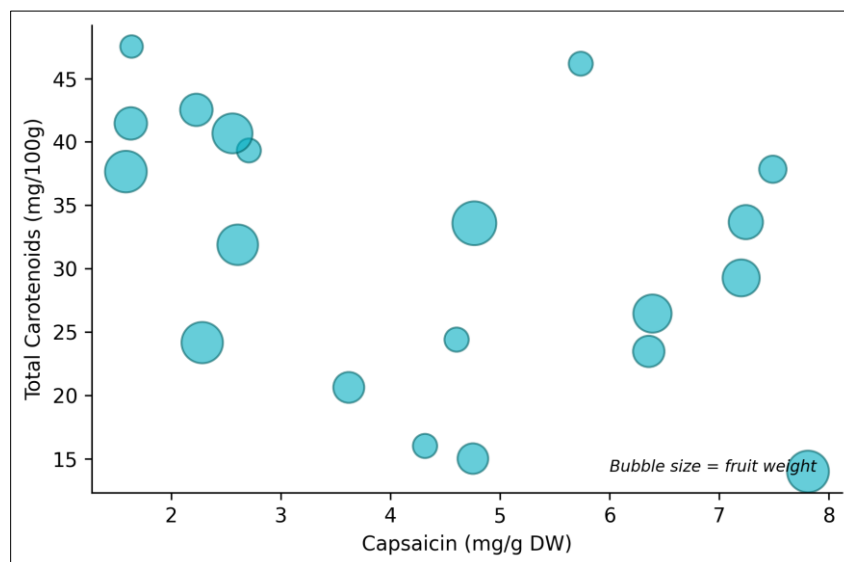


Fig 2: Bubble plot of capsaicin content versus total carotenoids, with bubble size proportional to individual fruit weight

Smaller fruits tended to carry higher capsaicin but also higher carotenoid levels, consistent with a concentration effect driven by reduced water content. The landrace produced the smallest but most pungent and pigmented fruits.

Discussion

The 64 percent improvement in water use efficiency under drip at 50 percent ETc compared with surface irrigation falls within the range reported for drip-irrigated vegetables in arid zones [4]. What makes this result notable is the simultaneous increase in capsaicin a quality trait that directly affects market value, since pungent varieties command premium prices in Indian spice markets [6]. The physiological mechanism appears to involve stress-induced upregulation of the phenylpropanoid pathway, channeling more phenylalanine toward capsaicinoid synthesis when carbon is not diluted by rapid fruit expansion [5].

Stomatal conductance declined by 34 percent under 50 percent ETc, confirming that plants experienced genuine water stress. But this did not translate into proportional yield loss, suggesting that chili pepper can maintain reasonable carbon assimilation even under reduced stomatal opening, possibly through osmotic adjustment or enhanced mesophyll conductance [13]. The Pun1 locus allele identified in the Rajsthani landrace was associated with a functional acyltransferase that catalyzes the final step in capsaicinoid biosynthesis a finding consistent with earlier molecular work in *C. annuum* [6].

Cowpea interplanting improved soil moisture retention by 12 percent, likely through surface shading that reduced evaporative loss from bare soil. Nodule counts averaged 28 per plant, and estimated biological nitrogen fixation contributed roughly 18 kg N/ha to the system a meaningful supplement in low-input Sahel agriculture [8]. Umami scores were 1.4 points higher in deficit-irrigated fruit (6.7 vs. 5.3 on a 9-point scale), a sensory dimension that may reflect higher glutamate concentrations in water-stressed tissues [14].

Conclusion

Drip irrigation at 50 to 75 percent of crop evapotranspiration doubled water use efficiency in chili pepper compared with surface irrigation, while simultaneously raising capsaicin and carotenoid levels. The Rajsthani landrace proved the most

pungent cultivar, carrying a favorable Pun1 allele that could be introgressed into improved lines through marker-assisted breeding. Cowpea cover cropping added soil moisture conservation and nitrogen benefits at minimal cost. For semi-arid chili growers, deficit drip irrigation paired with legume interplanting offers a practical, water-smart production strategy that improves both yield economics and fruit quality.

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