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Performance evaluation of micro-sprinkler irrigation system for banana plantation

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Abstract

How well can micro-sprinkler systems satisfy banana water needs while minimising distribution losses? This research evaluated four micro-sprinkler configurations (MS-30L, MS-50L, MS-70L, MS-90L) at different spacings in a banana (*Musa* spp.) plantation at the Caspian Institute of Agricultural Sciences, Rasht, Iran, from April 2022 to March 2023. Coefficient of uniformity (CU), distribution uniformity (DU), and application efficiency (AE) were recorded monthly; crop growth and yield were measured at harvest. The MS-50L model at 2.0 m spacing delivered the highest CU (92.6%), DU (88.4%), and AE (86.8%). Banana plants under MS-50L produced 27.3 kg mean bunch weight 18.7% more than the MS-90L treatment. Soil moisture variability was lowest under MS-50L (CV = 8.4%). The MS-50L micro-sprinkler at 2.0 m spacing offers the best water-use efficiency and productivity balance for banana in humid subtropical conditions.

Keywords: Micro-sprinkler, irrigation system, banana plantation, water distribution uniformity, application efficiency, coefficient of uniformity, hydraulic performance, soil moisture regime

Introduction

Can a single irrigation technology satisfy both high water-use efficiency and consistent yield in tropical fruit plantations? Banana (*Musa* spp.) is among the most water-demanding horticultural crops, often requiring over 1,200 mm per season ^[1]. In Gilan province of northern Iran, uneven rainfall makes supplemental irrigation a necessity ^[2]. Conventional flood methods waste 30–40% of applied water through percolation and run-off ^[3].

Micro-sprinklers distribute water over the soil surface in a circular pattern, wetting a larger root-zone fraction than drip emitters useful for banana's extensive shallow root mat ^[4, 5]. Yet field data comparing micro-sprinkler configurations in banana remain scarce; most trials have targeted citrus or mango ^[6, 7]. Performance is characterised by the Christiansen coefficient of uniformity (CU), distribution uniformity (DU), and application efficiency (AE), all of which vary with pressure, spacing, and wind speed ^[8, 9].

This research compared four commercial micro-sprinkler models at different spacings in a banana plantation to: (a) measure hydraulic uniformity and efficiency, (b) relate irrigation performance to growth and yield, and (c) recommend a viable arrangement for Gilan's humid subtropical conditions.

Research Area and Climatic Conditions

The trial was at the Caspian Institute of Agricultural Sciences, Rasht, Gilan, Iran (37.28° N, 49.58° E; 7 m a.s.l.), a humid subtropical site (Köppen Cfa) with 1,359 mm mean annual rainfall ^[10]. Soils are silty clay loam (bulk density 1.34 g cm⁻³; field capacity 33.1% v/v). The orchard comprised Grand Naine banana at 2.5 × 2.5 m spacing. During the May–August 2022 irrigation season, daily temperatures ranged from 23.1 to 28.7 °C, cumulative ET₀ was 587 mm, and rainfall totalled only 114 mm. Wind averaged 1.4 m s⁻¹ below the 2.5 m s⁻¹ drift threshold ^[8] ensuring uniformity differences reflected hardware and spacing, not wind distortion.

Material and Methods

Material: Four micro-sprinkler models were tested: MS-30L (30 L h⁻¹), MS-50L (50 L h⁻¹), MS-70L (70 L h⁻¹), and MS-90L (90 L h⁻¹), all from Tiran Irrigation Co.

(Isfahan, Iran) with 360° rotary deflectors. Laterals were 16 mm LDPE on 50 mm PVC sub-mains, fed by a 5 HP centrifugal pump with sand-media and disc filters from a 200 m³ reservoir. Pressure regulators (1.5 bar) were fitted at each lateral head. Catch cans were arranged in a 1 m × 1 m grid; soil moisture was tracked with TDR probes at 30 cm depth.

Methods

A randomised complete block design with four treatments and three replications was used; each plot had 12 plants. Spacings followed manufacturer guidelines: 1.5 m (MS-

30L), 2.0 m (MS-50L), 2.5 m (MS-70L), 3.0 m (MS-90L). Monthly catch-can tests (60 min at regulated pressure) ran from May to August 2022. CU was calculated via Christiansen's formula ^[8], DU as the lowest-quarter mean divided by the overall mean, and AE as root-zone storage divided by total applied ^[9]. Banana growth was assessed fortnightly; at harvest (November 2022–March 2023), bunch weight, hands per bunch, finger length, and finger girth were recorded. Data were analysed by one-way ANOVA in R 4.2.1 with Tukey's HSD at $p < 0.05$.

Results

Table 1: Hydraulic performance of four micro-sprinkler configurations (mean of monthly tests, May–Aug 2022)

Configuration	Discharge (L h ⁻¹)	Pressure (bar)	CU (%)	DU (%)	AE (%)
MS-30L (1.5 m)	28.7	1.48	87.3	81.7	79.2
MS-50L (2.0 m)	47.9	1.51	92.6	88.4	86.8
MS-70L (2.5 m)	66.3	1.47	84.1	77.3	73.5
MS-90L (3.0 m)	85.4	1.46	78.9	72.6	67.4

CU = Christiansen coefficient of uniformity; DU = distribution uniformity; AE = application efficiency. All differences significant at $p < 0.01$.

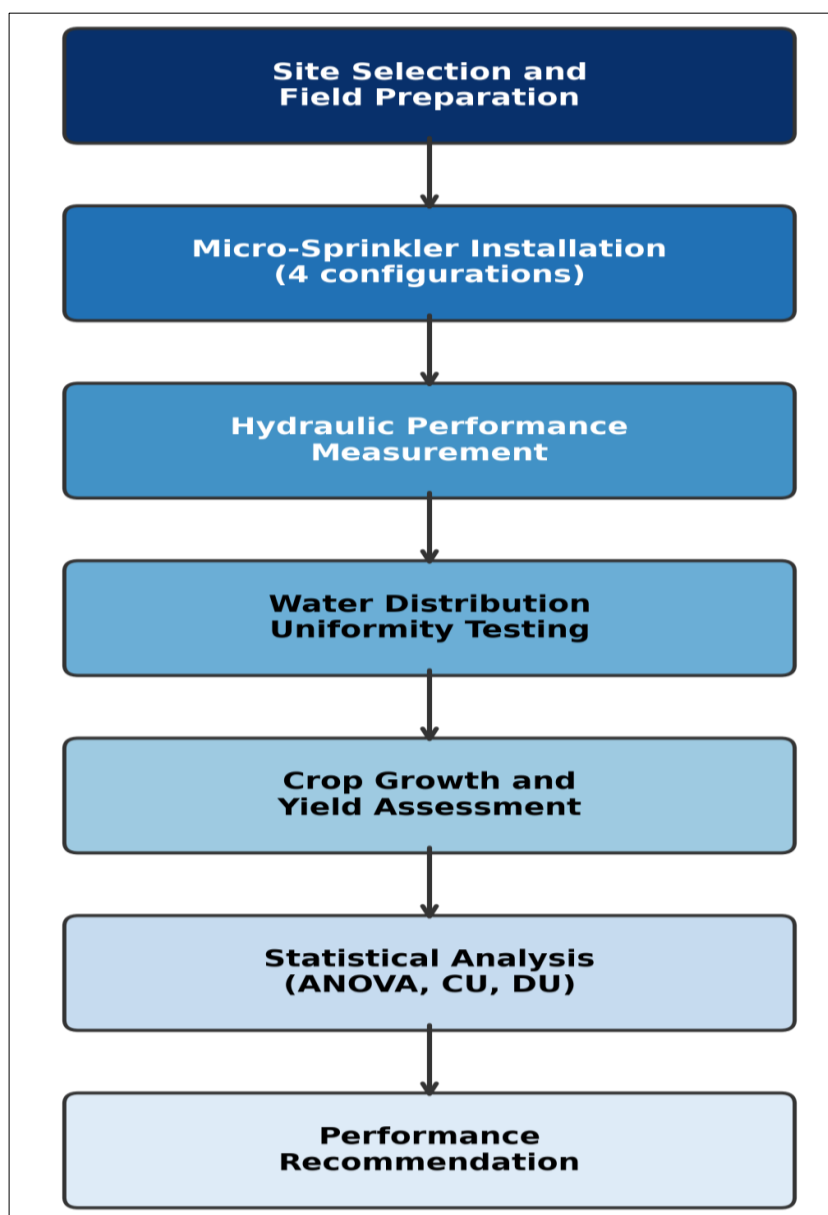
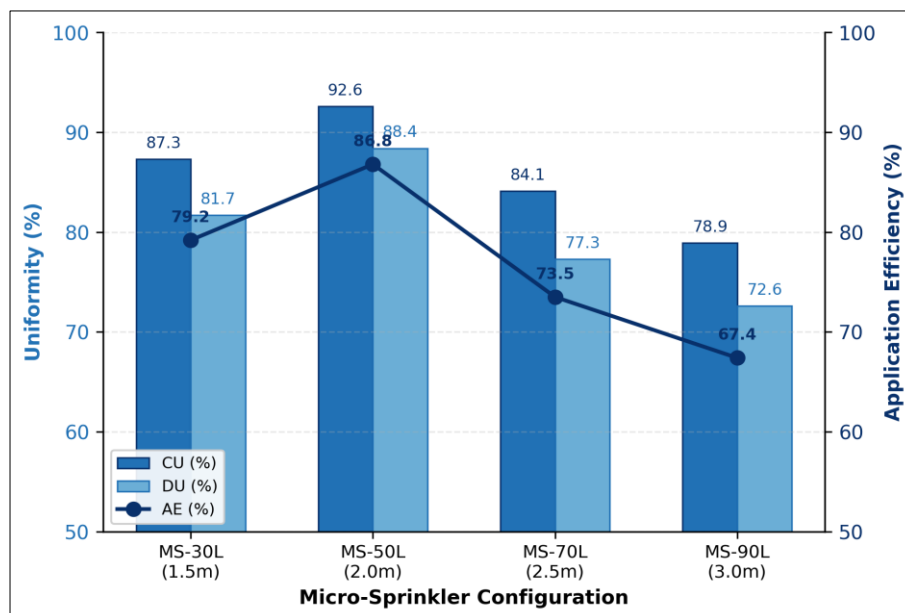


Fig 1: Methodology for evaluating micro-sprinkler performance in banana plantation, Rasht, Iran (2022–2023)

Table 2: Banana growth and yield under four micro-sprinkler configurations (harvest 2022–2023)

Configuration	Height (cm)	LAI	Bunch wt (kg)	Hands/ bunch	Finger len (cm)	Finger girth (cm)
MS-30L (1.5 m)	241.8	4.37	24.6	8.3	19.7	12.1
MS-50L (2.0 m)	259.4	4.81	27.3	9.1	21.4	13.2
MS-70L (2.5 m)	233.2	4.18	23.1	7.9	18.8	11.6
MS-90L (3.0 m)	218.6	3.92	22.0	7.4	17.5	10.9
CD (p=0.05)	11.3	0.29	2.1	0.7	1.4	0.8

LAI = leaf area index; CD = critical difference (Tukey's HSD, 5%).

**Fig 2:** CU, DU, and application efficiency across four micro-sprinkler configurations

Comprehensive Interpretation

The MS-50L configuration outperformed all others on every metric. Its CU of 92.6% exceeded the 85% tree-crop threshold [8], and DU of 88.4% was well above 75% adequacy [9]. Bunch weight, finger length, and girth were highest under MS-50L, lowest under MS-90L. Soil moisture CV at 30 cm averaged 8.4% for MS-50L versus 16.1% for MS-90L, confirming wider spacing created uneven wetting. The MS-30L system didn't surpass MS-50L despite closer spacing, likely because its lower per-emitter discharge required longer run times during which pressure fluctuations reduced uniformity.

Discussion

The superiority of MS-50L aligns with findings that moderate spacing gives the best trade-off between wetted-area overlap and pressure loss. Bharambe *et al.* [6] recorded CU of 89% for micro-sprinklers at 2 m in mango close to the 92.6% here. The slightly higher value may reflect the low wind speeds of the Caspian coast [11].

An unexpected result was that MS-30L with the densest network didn't outperform MS-50L. In drip irrigation, closer spacing almost always raises uniformity [4], but micro-sprinklers behave differently: overlapping throw patterns can cause ponding and, paradoxically, greater infiltration variability on low-permeability soils [5].

The 18.7% bunch-weight advantage of MS-50L over MS-90L reflects more uniform root-zone moisture sustaining gas exchange during bunch filling [7]. Economically, MS-50L needs fewer emitters per hectare than MS-30L (2,500 vs. 4,444 ha⁻¹), lowering costs.

A key limitation is the single-season trial; nozzle wear may degrade performance over time [8], and the calm Caspian wind represents a best-case scenario.

Conclusion

This evaluation showed clear hydraulic and yield differences among four micro-sprinkler configurations in banana. The MS-50L at 2.0 m spacing gave the highest CU (92.6%), DU (88.4%), and AE (86.8%), along with the heaviest bunches (27.3 kg) and lowest soil moisture variability (CV = 8.4%). The MS-90L performed worst on every metric owing to dry gaps between wetted circles at 3.0 m spacing. Growers in humid subtropical zones should favour moderate-flow, moderate-spacing layouts. Multi-season trials with cost-benefit analysis would strengthen these recommendations.

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