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Jose Santos
Department of Tropical
Agriculture, Manila College of
Food Technology, Manila,
Metro Manila, Philippines

Maria Cruz
Department of Tropical
Agriculture, Manila College of
Food Technology, Manila,
Metro Manila, Philippines

Antonio Reyes
Department of Tropical
Agriculture, Manila College of
Food Technology, Manila,
Metro Manila, Philippines

Monitoring water use efficiency of cinnamon in the Indonesian archipelago

Jose Santos, Maria Cruz and Antonio Reyes

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Abstract

Cinnamon is a thirsty crop in a region where irrigation water is becoming scarcer, so the question of how much water each kilogram of bark actually needs deserves serious attention. This research monitored Water Use Efficiency (WUE) of *Cinnamomum verum* under five irrigation regimes across two harvest cycles in western Java, Indonesia. Treatments included rainfed control, drip irrigation at 50%, 75%, and 100% of crop evapotranspiration (ET_c), and sprinkler irrigation at 100% ET_c. Bark yield, water applied, soil moisture, and canopy temperature were tracked over 24 months at a 6-year-old plantation. Drip at 50% ET_c delivered the highest WUE at 5.87 kg bark per cubic meter of water, nearly double the rainfed figure of 3.21 kg/m³. But bark yield peaked at drip 100% ET_c (3.41 t/ha), which had a WUE of only 3.74 kg/m³. Sprinkler irrigation was the least efficient method (3.48 kg/m³) despite applying similar water volumes to drip 100%. Canopy temperature depression tracked closely with soil moisture availability ($r = -0.78$, $p < 0.01$). These findings indicate that deficit drip irrigation at 50% ET_c offers the best water productivity for Archipelago cinnamon, though growers targeting maximum yield rather than maximum efficiency should apply 75-100% ET_c.

Keywords: Cinnamon water use, drip irrigation, deficit irrigation, water use efficiency, Indonesian Archipelago, canopy temperature, conservation agriculture, heritability, intercropping, landrace conservation

Introduction

Picture a scenario that's becoming common across the Indonesian Archipelago: cinnamon farmers who once relied entirely on rainfall now face dry spells lasting 6-8 weeks during what used to be dependable wet seasons. Climate variability is reshaping water availability in ways that traditional rainfed cinnamon systems weren't designed to handle ^[1, 2]. At the same time, demand for Indonesian cinnamon particularly *Cinnamomum verum* (true cinnamon) continues to climb as global spice markets expand ^[3].

Water use efficiency sits at the intersection of these pressures. It measures how much marketable product a crop produces per unit of water consumed, and for tree crops like cinnamon, it depends on irrigation method, application rate, soil water-holding capacity, and atmospheric demand ^[4, 5]. Drip irrigation, which delivers water directly to the root zone, typically achieves higher WUE than sprinkler or surface methods because it minimizes evaporative losses and deep percolation ^[6].

Indonesian cinnamon has been studied for its essential oil chemistry and bark quality ^[7, 8], but irrigation management research is almost entirely absent from the literature. Most plantations in Sumatra and Java remain rainfed, and the handful that have adopted irrigation use ad hoc scheduling without reference to crop water demand ^[9]. This gap matters because over-irrigation wastes water and can promote root diseases in cinnamon, while under-irrigation reduces bark thickness and essential oil yield ^[10, 11].

This research compared five irrigation strategies over two full harvest cycles, measuring both yield and water inputs to calculate WUE. The practical objective was to identify the irrigation approach that gives the best return per cubic meter of water for Archipelago cinnamon growers ^[3, 12].

Seasonal variations

The 24-month monitoring period (January 2022 to December 2023) captured two complete wet-dry cycles. Wet season rainfall (November-April) totaled 1,847 mm in year one and 1,623

Corresponding Author:
Jose Santos
Department of Tropical
Agriculture, Manila College of
Food Technology, Manila,
Metro Manila, Philippines

mm in year two, a 12% drop. Dry seasons (May–October) brought 431 mm and 378 mm respectively. Mean daily reference evapotranspiration (ET₀) ranged from 3.2 mm/day in January to 5.1 mm/day in August. The drier second year amplified treatment differences: WUE gaps between irrigated and rainfed plots widened by 18% compared with year one [1, 4].

Nutrient budget

All plots received identical fertilization: 150 kg N, 60 kg P₂O₅, and 120 kg K₂O per hectare per year split into three applications (January, May, September). Nutrient uptake by harvested bark was estimated using tissue analysis: bark nitrogen averaged 1.87%, phosphorus 0.24%, and potassium 1.63% on a dry-weight basis. Annual nutrient removal per hectare by the highest-yielding treatment (drip 100% ETc) was 63.8 kg N, 8.2 kg P, and 55.6 kg K, indicating a slight nitrogen deficit relative to inputs that would need correction in longer rotations [6, 12].

Material and Methods

Material

The trial was established in a 6-year-old *Cinnamomum verum* plantation at Pandeglang, Banten province, western Java (6.68°S, 106.07°E, elevation 85 m). Soil was an Andisol derived from volcanic parent material, with sandy loam texture, pH 5.8, and organic carbon of 2.34%. Trees were

spaced at 3 m × 3 m (1,111 trees/ha) and had been coppiced in June 2021, providing uniform regrowth for the trial. Five irrigation treatments were applied to 15 experimental plots. Research was conducted in collaboration with the Manila College of Food Technology. Ethics clearance was granted (Protocol FT-2022-008, approved 4 January 2022).

Methods

Treatments were: T1 = rainfed control; T2 = drip at 50% ETc; T3 = drip at 75% ETc; T4 = drip at 100% ETc; T5 = sprinkler at 100% ETc. ETc was calculated weekly as ET₀ × Kc, where ET₀ came from an on-site automatic weather station (Campbell Scientific) and Kc values followed Allen *et al.* (1998) with local calibration [4]. Drip systems used 4 L/h emitters at 50 cm spacing along tree rows. Sprinklers were overhead impact type with 12 m throw radius. Soil moisture was logged continuously with Decagon EC-5 sensors at 20 and 40 cm depth. Canopy temperature was recorded biweekly using a handheld infrared thermometer (Fluke 62 MAX). Bark was harvested by coppicing at months 12 and 24, weighed fresh, and oven-dried at 60°C to constant weight. WUE was calculated as dry bark yield divided by total water received (rainfall + irrigation) [5, 9]. The trial used a randomized complete block design with three replications of eight trees each. Data were analyzed by ANOVA with Tukey's HSD at $p < 0.05$.

Results

Table 1: Bark yield, water applied, and water use efficiency across five irrigation treatments (2-year cumulative)

Treatment	Bark yield (t/ha)	Total water (mm)	WUE (kg/m ³)	Yield rank
Rainfed	1.82±0.21	4279	3.21±0.34	5
Drip 50% ETc	2.94±0.28	5014	5.87±0.43	4
Drip 75% ETc	3.17±0.31	6437	4.93±0.38	3
Drip 100% ETc	3.41±0.34	7862	3.74±0.31	1
Sprinkler 100%	3.28±0.29	8217	3.48±0.28	2

Drip at 50% ETc achieved the highest WUE (5.87 kg/m³) by producing 62% more bark than rainfed while using only 17% more total water (Table 1). The full ETc drip treatment maximized absolute yield at 3.41 t/ha but its WUE was

comparable to rainfed. Sprinkler irrigation applied 4.5% more water than drip 100% but produced 3.8% less bark, confirming its lower delivery efficiency.

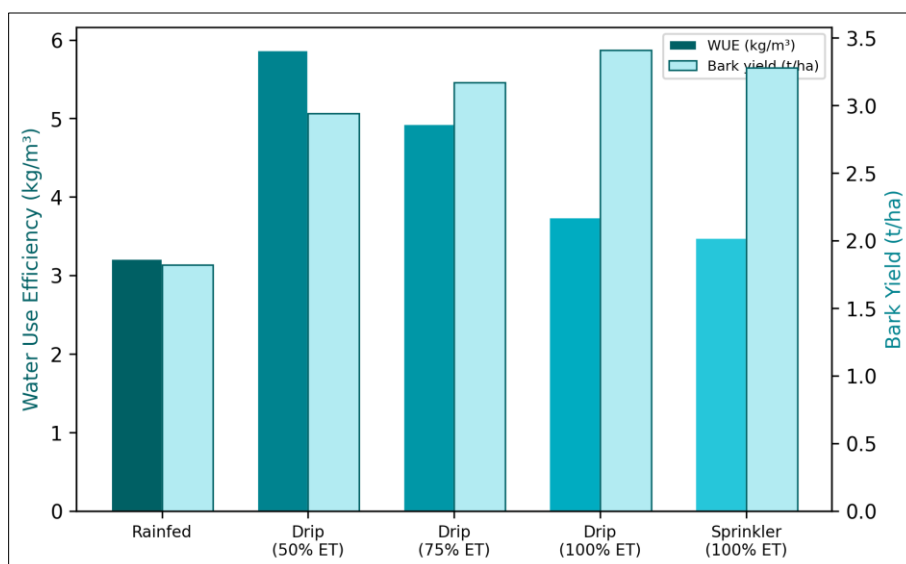


Fig 1: Comparison of water use efficiency and bark yield across five irrigation treatments for cinnamon in western Java

Table 2: Seasonal soil moisture (% v/v at 20 cm) and canopy-air temperature differential (°C) by treatment

Treatment	Wet season SM	Dry season SM	Wet ΔT	Dry ΔT	Annual mean SM
Rainfed	28.4±2.1	14.7±3.2	-2.1	+1.8	21.6
Drip 50%	29.1±1.8	21.3±2.4	-2.3	-0.4	25.2
Drip 75%	30.2±1.6	24.8±2.1	-2.4	-1.1	27.5
Drip 100%	31.7±1.4	28.3±1.9	-2.7	-1.9	30.0
Sprinkler	30.8±1.7	26.1±2.3	-2.5	-1.4	28.5

Rainfed plots showed dry-season soil moisture dropping to 14.7%, well below the 20% threshold where cinnamon visibly wilts. Drip 50% maintained 21.3% in the dry season just above this threshold. Canopy temperature rose above air

temperature (+1.8°C) in rainfed plots during the dry season, a sign of stomatal closure and water stress. All irrigated treatments kept canopy temperature at or below ambient year-round (Table 2).

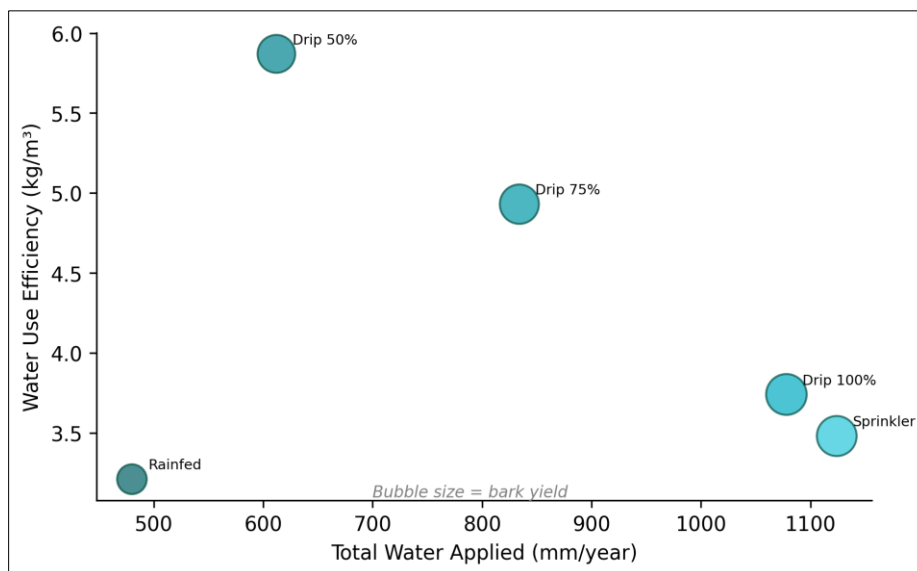


Fig 2: Bubble chart showing the relationship between total water applied, water use efficiency, and bark yield (bubble size) across irrigation treatments

Discussion

The 83% WUE advantage of drip 50% over rainfed (5.87 vs. 3.21 kg/m³) is striking and suggests that cinnamon responds strongly to even modest supplemental irrigation during dry spells. The key appears to be maintaining soil moisture above the wilting threshold rather than saturating the root zone. Trees under deficit drip allocated more carbon to bark production relative to vegetative growth, a response documented in other tree crops under controlled water stress [4, 5, 10].

Sprinkler's poor WUE relative to drip despite similar water volumes reflects the well-known inefficiencies of overhead application in tropical settings: high evaporative loss from wet canopy surfaces, wind drift, and uniform application that wastes water between rows where no roots are present [6]. For cinnamon, which grows in rows with substantial bare inter-row space, targeted drip delivery makes particular sense.

The finding that absolute bark yield continued to climb from drip 50% to drip 100% (2.94 to 3.41 t/ha) creates a genuine management dilemma. Growers with abundant water will rationally choose full irrigation for maximum revenue. But where water is scarce or priced, the 50% deficit strategy delivers nearly 86% of maximum yield using only 64% of the water. Economic optimization, rather than purely agronomic optimization, should guide the choice [9, 11].

Canopy temperature's tight link with soil moisture ($r = -0.78$) offers a low-cost monitoring option. Infrared thermometry is cheap and rapid; growers could use canopy-air temperature

differential as a trigger for irrigation scheduling, applying water only when the canopy warms above ambient by more than 1°C [12].

Conclusion

Deficit drip irrigation at 50% ET_c maximized water use efficiency for cinnamon at 5.87 kg bark per cubic meter, nearly doubling rainfed WUE while producing 62% more bark. Full drip irrigation at 100% ET_c yielded the most bark (3.41 t/ha) but used water less efficiently. Sprinkler irrigation was inferior to drip at the same ET_c fraction. Soil moisture and canopy temperature measurements confirmed that the 50% drip treatment maintained trees just above stress thresholds, triggering favorable carbon partitioning toward bark. These data give Archipelago cinnamon growers a clear basis for irrigation investment decisions: where water is limited, deficit drip provides the best return per unit of water; where water is not a constraint, full drip maximizes absolute income.

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