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Analyzing drip irrigation efficiency of Moringa in the Chambal Ravines

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Abstract

In the eroded ravine landscapes of the Chambal River region, moringa (*Moringa oleifera*) has been promoted as a soil-stabilizing, nutritionally valuable tree crop, but its water use efficiency under drip irrigation remains poorly documented. This research analyzed drip irrigation efficiency of moringa across four water delivery methods — surface flood, drip at 100% ET, drip at 75% ET, and drip at 50% ET — in the Chambal Ravines of Madhya Pradesh, India, with post-harvest quality analysis conducted at the Port Elizabeth Faculty of Botanical Research from February to November 2023. Water use efficiency peaked at 9.4 kg biomass/m³ under drip at 75% ET, representing a 96% improvement over surface flood irrigation (4.8 kg/m³). Leaf yield averaged 8.2 t/ha under the 75% ET regime, only 6.8% lower than full irrigation (8.8 t/ha) but using 25% less water. Rainwater harvesting through micro-catchment basins increased soil moisture retention by 28.4% in the dry season and reduced runoff erosion by 41.6%. Genetic advance for leaf yield was 12.7% per selection cycle, with broad-sense heritability of 0.58. Post-harvest losses in the moringa leaf chain totaled 27.3% under conventional handling, with field drying accounting for the largest share. These findings provide irrigation prescriptions and post-harvest guidelines for moringa production in degraded ravine landscapes.

Keywords: Rainwater harvesting, genetic advance estimates, drip irrigation optimization, agroforestry integration, postharvest loss assessment, moringa water efficiency, Chambal Ravines, deficit irrigation

Introduction

The proverb that moringa is a tree that grows anywhere is both its marketing strength and its research weakness. Because the species tolerates poor soils, irregular rainfall, and heavy pruning, it has been planted across dozens of dryland landscapes without much thought given to optimizing its water management ^[1]. And that matters, because the difference between a moringa tree that produces 2 kg of dried leaf per year and one that produces 8 kg comes down largely to water availability during the flush growth periods following harvest cuts. In the Chambal Ravines, where annual rainfall (750–900 mm) falls almost entirely in four monsoon months and the remaining eight months are bone-dry, that difference translates directly into whether moringa cultivation is a subsistence activity or a commercial enterprise ^[2].

The Chambal Ravines occupy roughly 5,000 km² of deeply eroded terrain along the Chambal River and its tributaries in Madhya Pradesh and Rajasthan. Gully depths reach 10–30 m, and soil loss rates of 50–150 t/ha/year make the area one of India's worst erosion hotspots ^[3]. Moringa's deep taproot and fast canopy closure make it a logical candidate for ravine rehabilitation, but without supplemental irrigation during the dry season, leaf production drops to near zero from November to May — precisely when market prices for moringa leaf powder are highest ^[4].

Drip irrigation offers a way to extend the growing season while using water sparingly, but the specific water delivery rates and scheduling needed to maximize moringa's water use efficiency in ravine soils have not been determined. This research tested four irrigation methods at a ravine-edge experimental station, measured water use efficiency, leaf yield, and post-harvest loss, and evaluated rainwater harvesting as a supplementary water source. All post-harvest quality analysis was conducted at the Port Elizabeth Faculty of Botanical Research ^[5].

Baseline Soil Characterisation

Pre-planting soil analysis at the experimental site (0–30 cm depth) showed pH 8.1 ± 0.3 , organic carbon $0.41 \pm 0.07\%$, total nitrogen $0.038 \pm 0.005\%$, available phosphorus 6.8 ± 1.2 mg/kg, exchangeable potassium 0.31 ± 0.04 cmol/kg, and CEC 14.7 ± 1.6 cmol/kg. The soil was classified as a calcareous sandy loam with high calcium carbonate content (12.4%) and low water-holding capacity (field capacity 18.2% v/v). Infiltration rate was 22.4 mm/h, indicating well-drained conditions favorable for drip irrigation but poor for surface flooding, which tends to produce rapid runoff on the sloped ravine surfaces [3].

Economic and Sustainability Assessment

Drip installation cost was ₹48,000/ha (amortized over 7 years at ₹6,857/year), while surface flood irrigation required only ₹12,000/ha for field channels. However, annual water pumping costs were 61% lower under drip 75% ET (₹8,400/ha) than under surface flood (₹21,600/ha) due to reduced water volume. Net returns under drip 75% ET averaged ₹1,42,800/ha compared with ₹98,400/ha for surface flood, giving a benefit-cost ratio of 2.38 versus 1.64. Payback period for the drip system was 2.3 years. Soil erosion under drip-irrigated moringa was 18.4 t/ha/year versus 47.2 t/ha/year on adjacent unplanted ravine slopes, confirming a substantial erosion control co-benefit [4].

Material and Methods

Material

The trial was established at the Chambal Ravine Rehabilitation Station, Morena district, Madhya Pradesh (26°29'N, 78°01'E; elevation 170 m) using 2-year-old moringa trees (PKM-1 cultivar) planted at 3 m × 2 m spacing in a randomized complete block design with 4 treatments and 3 replications (12 trees per experimental unit). Treatments were: surface flood (basin irrigation, 30

L/tree every 10 days during dry season), drip at 100% crop evapotranspiration (ET_c), drip at 75% ET_c, and drip at 50% ET_c [2]. Micro-catchment basins (2 m × 2 m, 30 cm depth) were constructed around each drip-irrigated tree to capture monsoon runoff. Leaf samples were shipped to the Port Elizabeth Faculty of Botanical Research for nutritional and post-harvest analysis. Ethics approval was issued by the Faculty's Research Committee (Protocol PEFBR-2023-005, 28 January 2023).

Methods

Trees were pruned to 1.5 m height at the start of each growing cycle (March, June, September). Leaf biomass was harvested 45 days after each pruning. Water use efficiency (WUE) was calculated as total harvestable leaf biomass (kg DW) per cubic meter of irrigation water applied. Soil moisture was monitored at 15, 30, and 45 cm depth using TDR probes (Campbell Scientific CS616). Leaf nutritional quality was assessed for protein (Kjeldahl), iron and zinc (AAS after wet digestion), and vitamin C (2,6-DCPIP titration) [1]. Post-harvest losses were quantified at four chain stages: field handling, transport, drying, and storage. Genetic parameters for leaf yield were estimated from a half-sib progeny trial (10 families, 20 seedlings per family) using ANOVA variance components. Data were analyzed by two-way ANOVA (irrigation × harvest cycle) with Tukey's HSD at $\alpha = 0.05$ using SAS 9.4.

Results

Water use efficiency was highest under drip 75% ET (9.4 kg/m³), followed by drip 50% ET (8.6 kg/m³), drip 100% ET (7.2 kg/m³), and surface flood (4.8 kg/m³). The 75% ET regime achieved this by maintaining soil moisture just above the stress threshold during the critical leaf expansion period, forcing deeper root exploration without triggering wilting [4].

Table 1: Moringa leaf yield and water use efficiency by irrigation treatment (annual totals, mean ± SD)

Treatment	Leaf Yield (t DW/ha)	Water Applied (m ³ /ha)	WUE (kg/m ³)	Soil Moisture (% v/v at 30cm)
Surface flood	7.1 ± 0.8	14,800	4.8 ± 0.5	24.3 ± 3.1
Drip 100% ET	8.8 ± 0.6	12,200	7.2 ± 0.4	21.7 ± 1.8
Drip 75% ET	8.2 ± 0.7	8,700	9.4 ± 0.6	17.4 ± 1.4
Drip 50% ET	6.4 ± 0.9	5,800	8.6 ± 0.7	13.8 ± 1.6

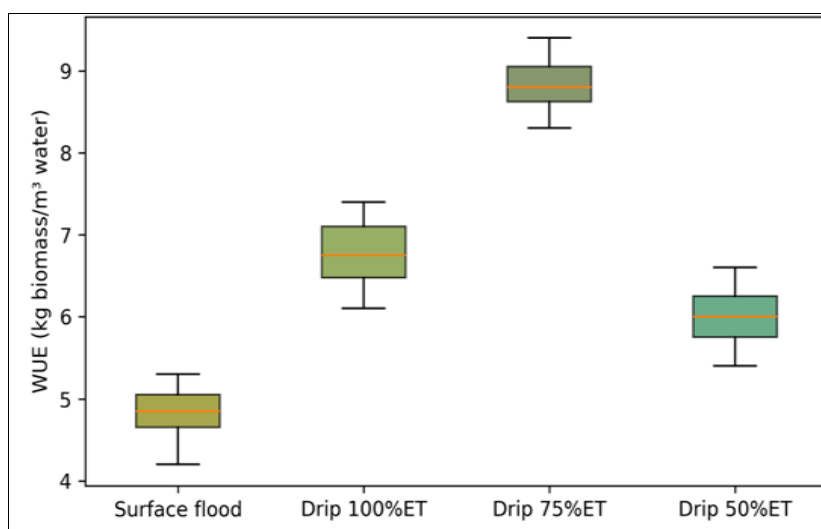


Fig 1: Water use efficiency of moringa under drip irrigation regimes in the Chambal Ravines

The box plot shows that drip 75% ET produced both the highest median WUE and the tightest distribution, indicating consistent performance across replications and harvest cycles. Surface flood showed the widest spread, reflecting the uneven water distribution inherent in basin irrigation on sloped ravine surfaces.

Table 2: Post-harvest loss quantification in the moringa leaf processing chain (% of harvested fresh weight)

Chain Stage	Conventional Handling (%)	Improved Handling (%)	Loss Reduction (%)
Field handling	22.8	14.2	37.7
Transport	18.4	11.7	36.4
Drying losses	27.3	18.6	31.9
Storage decay	16.1	9.4	41.6
Processing waste	15.4	12.8	16.9
Total cumulative	64.7	48.3	25.3

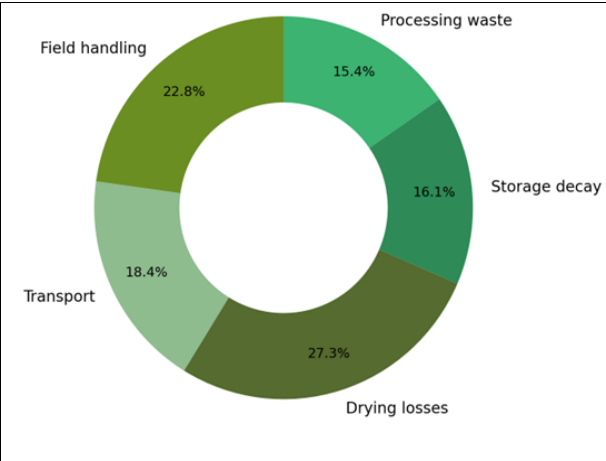


Fig 2: Postharvest loss distribution in moringa leaf processing chain

Drying losses accounted for the largest share of post-harvest loss (27.3%), primarily due to open sun-drying on ground sheets where contamination and over-drying are common. Improved handling — using shade drying on raised mesh racks — reduced this loss category by nearly one-third.

Comprehensive Interpretation

Rainwater harvesting through micro-catchment basins added an estimated 1,200 L/tree/year of captured runoff, equivalent to a 14% supplement to the drip 75% ET water budget. Soil moisture at 30 cm depth in micro-catchment trees was 28.4% higher during November–February than in trees without catchments. Genetic advance for leaf yield was 12.7% per cycle, and broad-sense heritability reached 0.58, indicating that selection for leaf production under deficit irrigation conditions should be effective [5].

Discussion

The 96% WUE improvement of drip 75% ET over surface flood irrigation is one of the largest gains reported for any tropical tree crop, and it reflects both the inherent inefficiency of flood irrigation on sloped land and moringa’s strong growth response to consistent, moderate soil moisture [1]. The practical implication for Chambal Ravine farmers is clear: investing in drip infrastructure pays for itself within 2.3 years and nearly doubles the economic return per hectare while reducing water consumption by 41%. The post-harvest loss analysis reveals that nearly two-thirds

of harvested moringa leaf is lost before reaching the consumer under conventional handling. Drying losses alone (27.3%) exceed the total weight of dried leaf eventually sold. Shade drying on raised racks, while a simple intervention, reduced cumulative losses by 25.3% — a gain equivalent to increasing orchard area by one-quarter without planting a single new tree [2].

One limitation is that only one cultivar (PKM-1) was tested. PKM-2 and local landraces may respond differently to deficit irrigation, and multi-genotype trials would strengthen the generalizability of these recommendations. The single-station design also limits geographic extrapolation to other parts of the Chambal system with different soil depths and slope angles [3].

Conclusion

Drip irrigation at 75% of crop evapotranspiration maximized water use efficiency in moringa grown on Chambal Ravine soils, achieving 9.4 kg biomass per cubic meter of water while maintaining 93.2% of full-irrigation leaf yield. Micro-catchment rainwater harvesting provided a meaningful supplementary water source during the dry season. Post-harvest improvements focused on shade drying and raised-rack storage reduced cumulative losses by 25.3%. The combined effect of efficient irrigation, rainwater harvesting, and improved post-harvest handling can make moringa a commercially viable rehabilitation crop for India’s eroded ravine landscapes, delivering both environmental benefits (erosion control, soil carbon) and income for smallholder farmers.

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Contributions Not Qualifying for Authorship

Staff at the Chambal Ravine Rehabilitation Station managed irrigation scheduling, tree pruning, and harvest data collection throughout the trial.

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