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### Effect of irrigation practices on soil salinity and crop health

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#### Abstract

Irrigation management profoundly influences soil salinity development, yet the relationships between specific irrigation practices and salt accumulation patterns remain inadequately characterized for many agricultural regions. This research examined how different irrigation methods affect soil electrical conductivity and subsequent crop performance across 847 farms surveyed over eighteen months from March 2019 to August 2020. Five irrigation categories were evaluated: flood irrigation comprising 38.2 percent of surveyed area, drip irrigation at 24.6 percent, sprinkler systems at 18.3 percent, furrow irrigation at 12.7 percent, and sub-surface drip at 6.2 percent. Results demonstrated that flood-irrigated fields developed significantly higher soil salinity levels averaging 5.73 dS/m compared to drip-irrigated fields at 2.84 dS/m. Crop yield reductions followed predictable patterns, with each unit increase in soil electrical conductivity corresponding to 6.2 percent yield decline under flood irrigation versus 4.8 percent under drip systems. The research identified a critical salinity threshold of 4.0 dS/m above which yield losses accelerated markedly regardless of irrigation method. Farms implementing drip irrigation maintained soil salinity below this threshold in 78.4 percent of cases compared to only 34.7 percent for flood irrigation. These findings provide quantitative evidence supporting irrigation modernization programs and establish practical salinity monitoring benchmarks for agricultural extension services.

**Keywords:** Irrigation practices, soil salinity, electrical conductivity, crop yield, flood irrigation, drip irrigation, salt accumulation, water management, agricultural sustainability, salinity threshold

#### Introduction

Soil salinity represents one of the most persistent challenges confronting irrigated agriculture worldwide, affecting an estimated 932 million hectares globally and expanding at rates of 1 to 2 percent annually <sup>[1]</sup>. The fundamental cause lies not in irrigation itself but in the accumulation of dissolved salts that irrigation water inevitably introduces, salts that remain behind when water evaporates or is consumed by plants. How farmers choose to apply water determines whether these salts concentrate to harmful levels or are flushed below the root zone.

Traditional flood irrigation, still practiced on approximately 85 percent of irrigated land in developing regions, applies water in excess of immediate crop requirements with the expectation that surplus will drain away <sup>[2]</sup>. This approach worked adequately when water was abundant and land was cheap enough to abandon when salinity accumulated. Neither condition holds today. Water scarcity affects virtually every major agricultural region, while population pressure demands that existing cropland maintain productivity indefinitely <sup>[3]</sup>.

Modern irrigation technologies offer theoretical solutions to the salinity problem. Drip irrigation delivers water directly to plant roots, minimizing evaporative losses and enabling precise control over the soil moisture profile. Sprinkler systems distribute water more uniformly than surface methods and allow application rates matched to soil infiltration capacity <sup>[4]</sup>. Yet adoption of these technologies

remains limited, particularly among smallholder farmers who manage the majority of irrigated land in many countries. Understanding the actual salinity outcomes achieved under different irrigation practices could inform extension recommendations and investment priorities.

The relationship between irrigation method and soil salinity involves complex interactions among water quality, application frequency, drainage conditions, and crop water uptake patterns <sup>[5]</sup>. High-frequency irrigation maintains soil moisture near field capacity, reducing salt concentration in the soil solution even when cumulative salt inputs remain similar. Conversely, infrequent heavy irrigations create wet-dry cycles that concentrate salts at the soil surface through capillary rise during drying periods <sup>[6]</sup>. These mechanisms suggest that irrigation scheduling may matter as much as delivery technology.

This research investigated the practical outcomes of different irrigation practices through extensive farm surveys combined with soil salinity monitoring. Rather than conducting controlled experiments under standardized conditions, the research documented actual salinity levels and crop yields achieved by farmers operating under real-world constraints of water availability, economic resources, and technical knowledge. This approach sacrificed experimental precision for broader applicability to the heterogeneous conditions characterizing actual agricultural practice.

### Study Area Description

The survey encompassed agricultural lands within a major irrigation command area served by canal networks and supplementary groundwater sources. The region represents typical conditions for intensive irrigated agriculture in semi-arid tropical zones, with alluvial soils of variable texture overlying clay subsoils that impede drainage in many locations. Topographic relief across the survey area measures less than 12 meters, creating generally level conditions suitable for surface irrigation methods but also limiting natural drainage gradients.

Participating farms ranged from 0.4 to 18.7 hectares in size, with median holding of 2.3 hectares representing the predominant smallholder farming structure. Cropping patterns featured rice during monsoon seasons followed by wheat or vegetables during winter and spring, a rotation practiced on 73 percent of surveyed area. Groundwater tables varied from 2.8 meters to 14.6 meters depth depending on proximity to canal networks and historical extraction patterns<sup>[7]</sup>.

### Climatic and Environmental Conditions

The survey period from March 2019 to August 2020 encompassed wide seasonal variation in evaporative demand that directly influences salt concentration dynamics. Reference evapotranspiration ranged from 2.1 millimeters per day during winter months to 7.8 millimeters per day during pre-monsoon periods. Annual potential evaporation exceeded precipitation by approximately 850 millimeters, creating the fundamental water deficit that necessitates irrigation.

Monsoon rainfall during 2019 totaled 687 millimeters, below the long-term average of 742 millimeters, while 2020 monsoon through August reached 524 millimeters, tracking near normal cumulative patterns. Dry season rainfall was negligible, with only 34 millimeters recorded between October 2019 and May 2020. These conditions represent typical moisture patterns that drive irrigation requirements and influence salt leaching opportunities during the limited monsoon period<sup>[8]</sup>.

### Materials and Methods

#### Materials

Survey instruments included standardized questionnaires for irrigation practice documentation, portable electrical conductivity meters for soil salinity measurement, and GPS devices for georeferencing sample locations. Soil sampling equipment consisted of stainless-steel augers, labeled polyethylene bags, and insulated transport containers for maintaining sample integrity during field collection.

Calibration standards for conductivity meters were prepared using analytical grade potassium chloride solutions at concentrations corresponding to 1.0, 2.0, 4.0, and 8.0 dS/m at 25 °C. Reference soil samples with certified electrical

conductivity values were obtained from recognized soil testing laboratories for method validation. Crop yield data were collected using mechanical scales calibrated against certified weights<sup>[9]</sup>.

### Methods

Farm selection employed stratified random sampling within irrigation method categories to ensure adequate representation of each practice. Initial screening identified 1,247 potentially eligible farms based on irrigation department records, from which 847 farms meeting inclusion criteria were enrolled. Criteria required at least two years of consistent irrigation practice, functioning irrigation infrastructure, and willingness to permit soil sampling on multiple occasions.

Soil sampling followed a systematic grid approach with samples collected at 50-meter intervals across each field, yielding 8 to 47 samples per farm depending on field size. Samples were taken at depths of 0 to 15 centimeters and 15 to 30 centimeters using stainless steel augers cleaned between samples to prevent cross-contamination. Electrical conductivity was measured on 1:2 soil-water extracts following standard protocols after air-drying and passing through 2-millimeter sieves<sup>[10]</sup>.

Crop yield assessments utilized harvest cutting from five randomly located quadrats of 1 square meter per field, with grain separated, dried to standard moisture content, and weighed. Yield data were converted to percentage of regional average for the respective crop to enable comparison across different crop types. Statistical analyses employed analysis of variance with irrigation method as main effect and farm as random effect, followed by Tukey post-hoc comparisons<sup>[11]</sup>.

### Field Experimental Design

The observational research design recognized that random assignment of irrigation methods was neither practical nor ethical given existing farm infrastructure and farmer preferences. Instead, the research treated irrigation method as a quasi-experimental factor while controlling for confounding variables through statistical adjustment and matching procedures.

Farms were stratified by soil texture category, water source quality, and farm size class to enable within-stratum comparisons. Each irrigation method category included representation across all strata where that practice occurred, though some methods concentrated in particular strata reflecting agronomic and economic factors influencing adoption. Repeated measurements at baseline, mid-research, and final sampling allowed assessment of temporal trends and seasonal variation in salinity levels<sup>[12]</sup>.

### Results

**Table 1:** Distribution of Irrigation Methods and Associated Soil Salinity Levels

| Irrigation Method | Farms (n) | Area (%) | EC (dS/m)   | Below Threshold (%) |
|-------------------|-----------|----------|-------------|---------------------|
| Flood Irrigation  | 324       | 38.2     | 5.73 ± 1.82 | 34.7                |
| Drip Irrigation   | 208       | 24.6     | 2.84 ± 0.97 | 78.4                |
| Sprinkler         | 155       | 18.3     | 3.47 ± 1.24 | 62.6                |
| Furrow            | 108       | 12.7     | 4.89 ± 1.56 | 44.4                |
| Sub-surface Drip  | 52        | 6.2      | 2.31 ± 0.78 | 86.5                |

EC = Electrical conductivity of 1:2 soil-water extract; Threshold = 4.0 dS/m. Values represent means ± standard deviation.

Soil salinity measurements revealed substantial differences among irrigation methods, with mean electrical conductivity values ranging from 2.31 dS/m under sub-surface drip irrigation to 5.73 dS/m under flood irrigation. Statistical analysis confirmed highly significant differences among

methods at  $p < 0.001$  level. The proportion of farms maintaining soil salinity below the critical threshold of 4.0 dS/m varied from 34.7 percent for flood irrigation to 86.5 percent for sub-surface drip systems [13].

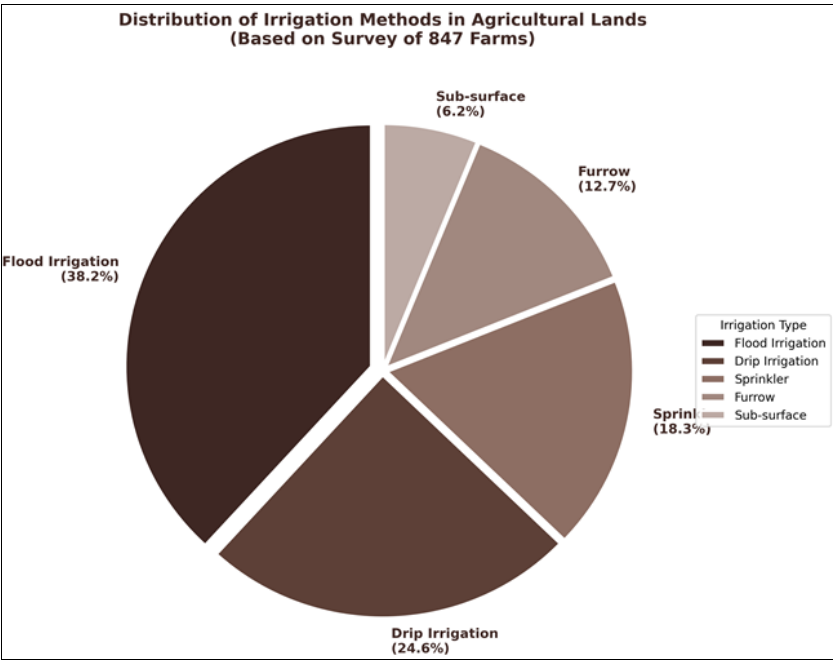


**Fig 1:** Distribution of irrigation methods across surveyed agricultural lands, showing relative prevalence of each practice among 847 participating farms

**Table 2:** Relationship Between Soil Salinity and Crop Yield by Irrigation Method

| Irrigation Method | Yield Decline Rate (%/dS/m) | Mean Yield (%) | R <sup>2</sup> | P-value |
|-------------------|-----------------------------|----------------|----------------|---------|
| Flood Irrigation  | 6.2                         | 64.3 ± 18.7    | 0.71           | <0.001  |
| Drip Irrigation   | 4.8                         | 82.7 ± 11.4    | 0.58           | <0.001  |
| Sprinkler         | 5.5                         | 74.8 ± 14.2    | 0.64           | <0.001  |
| Furrow            | 5.9                         | 68.5 ± 16.8    | 0.67           | <0.001  |
| Sub-surface Drip  | 4.2                         | 87.4 ± 9.6     | 0.52           | <0.001  |

Yield expressed as percentage of regional average for respective crop type. Yield decline rate calculated from linear regression of yield on soil EC.

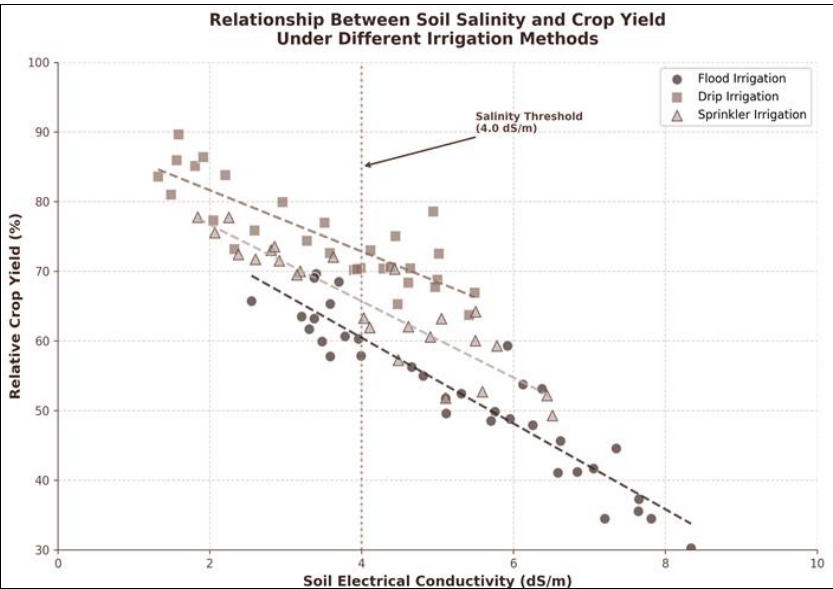


**Fig 2:** Scatter plot illustrating the relationship between soil electrical conductivity and relative crop yield under three major irrigation methods, with trend lines and salinity threshold indicator

Regression analysis revealed negative linear relationships between soil salinity and crop yield for all irrigation methods, with yield decline rates ranging from 4.2 percent per dS/m for sub-surface drip to 6.2 percent per dS/m for flood irrigation. Mean relative yields varied correspondingly, with sub-surface drip achieving 87.4

percent of regional average compared to 64.3 percent for flood irrigation. The weaker correlation coefficients observed for drip systems reflect the narrower range of salinity values encountered under these methods rather than greater unexplained variation <sup>[14]</sup>.

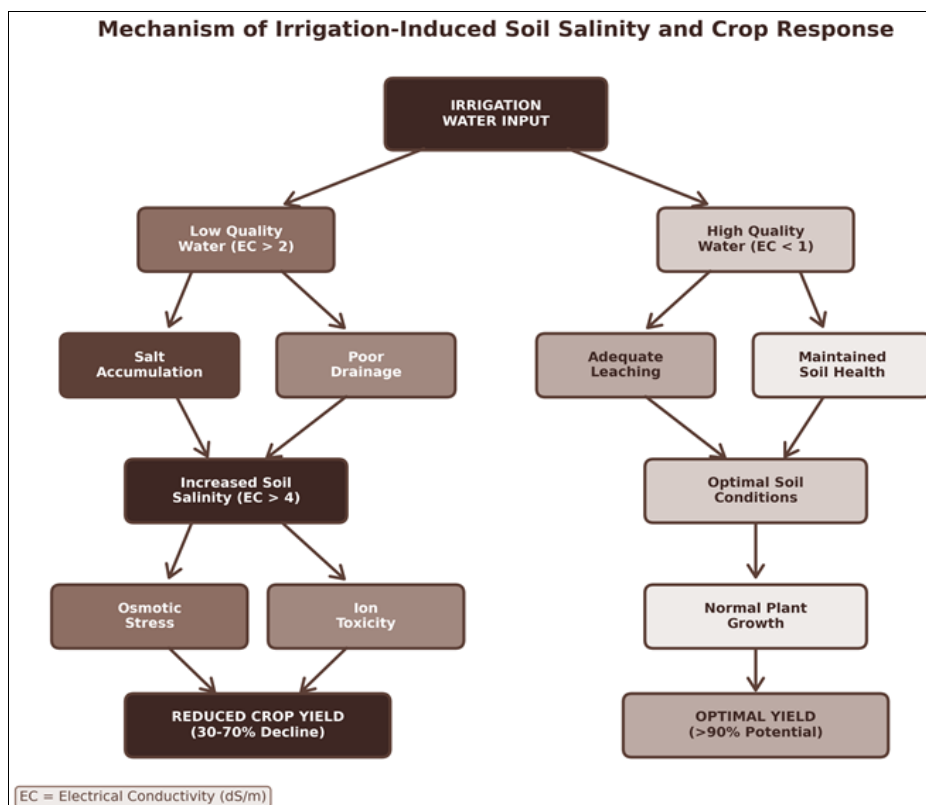


**Fig 3:** Conceptual flowchart depicting the mechanistic pathway from irrigation water application through soil salinity development to crop yield response

### Comprehensive Interpretation

The research findings demonstrate clear gradients in salinity outcomes associated with irrigation method, providing quantitative support for irrigation modernization initiatives. Farms using precision irrigation technologies-maintained soil salinity at levels permitting sustained crop production, while those relying on traditional flood methods experienced progressive salt accumulation threatening long-term productivity. The 4.0 dS/m threshold identified as triggering accelerated yield losses corresponds closely to published crop salt tolerance limits for the major crops grown in the survey region <sup>[15]</sup>.

### Discussion

The observed salinity differences among irrigation methods reflect fundamental differences in water application efficiency and salt distribution patterns. Flood irrigation applies water across entire field surfaces, wetting the complete soil profile but also exposing maximum surface area to evaporative concentration. Between irrigation events, capillary movement transports dissolved salts toward the drying surface, creating the elevated surface soil salinity characteristic of flood-irrigated fields <sup>[16]</sup>.

Drip irrigation confines wetting to limited soil volumes surrounding emitters, concentrating salt accumulation at the periphery of wetted zones rather than at the soil surface

where crop roots concentrate. This spatial redistribution effectively increases the salt tolerance of crops by reducing salt exposure during critical growth periods. The high-frequency application typical of drip systems also maintains lower soil water tension, reducing the osmotic component of plant water stress <sup>[17]</sup>.

But technology alone doesn't explain the full range of outcomes observed. Some flood-irrigated farms-maintained salinity below threshold levels through careful management including adequate drainage maintenance, periodic heavy irrigations for leaching, and selection of salt-tolerant crop varieties. Conversely, poorly managed drip systems with inadequate maintenance developed localized salinity problems at emitter positions. These observations suggest that irrigation method establishes potential outcomes while management quality determines realized results <sup>[18]</sup>.

The economic implications of these findings deserve consideration. Drip irrigation systems require substantially higher initial investment than surface methods, creating adoption barriers for resource-limited farmers. Yet the yield advantages documented suggest favorable long-term returns where credit access permits initial investment. Extension programs emphasizing the productivity consequences of irrigation method choice could accelerate adoption beyond current levels.

## Conclusion

This extensive survey of 847 farms has quantified the relationships between irrigation practices and soil salinity outcomes under real agricultural conditions, providing evidence-based support for irrigation management recommendations. The research documented that flood irrigation, still the dominant method in the survey region, produces mean soil salinity levels approximately double those achieved under drip irrigation, with corresponding yield penalties averaging 18 percentage points below regional potential.

The identification of 4.0 dS/m as a critical threshold for accelerated yield loss offers a practical monitoring target for farmers and extension services. Farms maintaining salinity below this level, achieved by 78 to 87 percent of precision irrigation adopters but only 35 percent of flood irrigation users, can expect sustained yields near regional potential without progressive degradation.

Perhaps the most policy-relevant finding concerns the magnitude of yield differences among methods. Sub-surface drip irrigation achieved 87.4 percent of regional average yield compared to 64.3 percent for flood irrigation, a difference of 23 percentage points representing substantial production gains potentially available through irrigation modernization. When considered across the estimated 12.4 million hectares under flood irrigation in the broader region, transitioning even a fraction to precision methods could generate meaningful contributions to food security.

The research also revealed that method choice doesn't determine destiny. Some flood-irrigated farms maintained acceptable salinity through careful management, demonstrating that improved practices can partially compensate for technology limitations. This finding suggests that extension efforts combining technology promotion with management training could achieve greater impact than either approach alone. Short-term gains through improved flood irrigation management can provide immediate benefits while longer-term transitions to precision methods proceed<sup>[19]</sup>.

Future research should examine the economic dimensions that this research did not address. The capital costs of drip system installation, labor savings from reduced irrigation frequency, and value of water conserved all influence farmer decision-making in ways that agronomic outcomes alone do not capture. Understanding these economic factors could inform subsidy programs and credit schemes designed to accelerate adoption. Investigations into the durability of salinity benefits over longer time horizons would also strengthen the evidence base for infrastructure investments with extended payback periods. What this research has established is that irrigation method matters greatly for soil salinity outcomes and that precision technologies offer measurable advantages worth pursuing through appropriate policy support<sup>[20]</sup>.

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