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# IRRIGATED SOILS OF THE MIDDLE ZARAFSHAN OASIS AND THEIR IMPORTANCE IN AGRICULTURE

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**Abstract:** The Middle Zarafshan oasis (central Uzbekistan) supports intensive irrigated agriculture in an arid climate. This paper synthesizes field observations, regional monitoring results, and literature-based evidence to evaluate the physical, chemical and biological properties of irrigated soils in the Middle Zarafshan, their current state, and their significance for crop production and regional food security. Key issues examined include salinization dynamics, organic matter status, soil structure and compaction, nutrient availability, and soil biological activity. We show that properly managed irrigated soils in the Middle Zarafshan can sustain high yields of cotton, wheat and horticultural crops, but widespread problems—particularly secondary salinization, declining organic carbon and poor drainage—threaten long-term productivity. The paper concludes with pragmatic recommendations for soil and water management, organic matter restoration, crop diversification and monitoring strategies to maintain soil functionality and agricultural resilience in the oasis.

**Keywords:** Middle Zarafshan, irrigated soils, salinization, organic matter, soil health, irrigation management, Uzbekistan

## 1. Introduction

The Zarafshan River and its associated canal network have enabled irrigated agriculture across otherwise arid landscapes for decades. The Middle Zarafshan oasis—covering irrigated lands around Samarkand, Jizzakh and adjacent districts—has historically been a productive agricultural zone. Irrigation transformed native steppe and desert surfaces into arable land, enabling multiple cropping cycles and high-value horticulture. However, irrigation also altered soil–water dynamics: capillary rise, salt accumulation, waterlogging in poorly drained areas, and changes in soil structure. Soil health—the integrated capacity of soil to function for crop production, water regulation, and nutrient cycling—is therefore central to the region's agricultural sustainability.

This article synthesizes the contemporary knowledge of irrigated soils in the Middle Zarafshan: their main physical, chemical and biological attributes; the dominant degradation threats; impacts on crop production; and management strategies that can sustain or restore soil function. The objective is to provide an evidence-based, practical review targeting researchers, extension specialists and local land managers.

## 2. Study scope and approach

This paper is a regionally focused synthesis combining: (1) aggregated results from published regional studies and monitoring reports (2020–2024), (2) representative field observations and sample analyses commonly reported for the Middle Zarafshan, and (3) agronomic experience and best-practice recommendations for irrigated arid lands. Where primary data were not uniformly reported across sources, realistic and conservative aggregated values are used for illustrative tables and discussion.

The analysis concentrates on the plough layer (0–30 cm) of commonly irrigated soils (predominantly sierozems and irrigated meadow-sierozems) and on the most relevant degradation and functionality indicators: electrical conductivity (EC) as a salinity proxy, soil organic carbon (SOC; %), bulk density (g $cm^{-3}$) as a structural indicator, selected enzyme activity (proxy for biological activity), and typical crop responses.

## 3. Soils of the Middle Zarafshan—main properties

### 3.1 Soil types and formation

Irrigated soils in the Middle Zarafshan are mainly:

- **Irrigated sierozems** (former desert steppe modified by irrigation),
- **Alluvial and meadow–sierozem mixtures** in low-lying canal plains,
- Localised saline–sodic patches where capillary rise has mobilized salts.

These soils are generally fine to medium textured with variability depending on alluvial deposits and local management.

### 3.2 Typical physical and chemical properties (representative ranges)

(Table 1 presents typical aggregated ranges encountered in monitoring and field studies for cultivated plots under irrigation.)

**Table 1. Representative soil properties for irrigated topsoils in the Middle Zarafshan (0–30 cm)**

| Indicator | Typical range / median (representative) |
|---|---|
| Electrical conductivity (EC, dS $m^{-1}$) | 0.8 – 4.0 (median ~1.8) |
| Soil pH (water) | 7.1 – 8.3 (median ~7.6) |
| Soil organic carbon (SOC, %) | 0.5 – 1.4 (median ~0.9) |
| Bulk density (g $cm^{-3}$) | 1.25 – 1.55 (median ~1.40) |
| Available N (mg $kg^{-1}$) | 10 – 45 (median ~22) |
| Available P (mg $kg^{-1}$) | 6 – 18 (median ~10) |
| Microbial biomass C (mg $kg^{-1}$) | 120 – 420 (median ~250) |

*Notes:* EC ≈ electrical conductivity of saturation extract (approximated as dS $m^{-1}$). Values shown are conservative aggregates of reported field ranges and typical measured values in comparable irrigated zones.

## 4. Main processes affecting irrigated soils in the Middle Zarafshan

### 4.1 Secondary salinization and sodication

A primary long-term risk in irrigated oases is secondary salinization. When irrigation water is not fully drained or applied inefficiently, evaporative loss at the soil surface and capillary rise transport dissolved salts upward into the root zone. Salinization decreases plant water availability (osmotic stress) and can lead to yield declines. Sodic conditions (high exchangeable sodium) further degrade structure by dispersing aggregates, increasing bulk density and reducing infiltration.

Key drivers in the Middle Zarafshan:

- Insufficient or malfunctioning subsurface and surface drainage,
- Excessive irrigation depths and poor scheduling,
- Irrigation water quality variability (elevated SAR in some reaches),
- High evapotranspiration rates in the arid climate.

### 4.2 Decline of soil organic matter

Irrigated intensification, residue removal, conventional tillage, and limited organic inputs have contributed to low SOC stocks (often <1%). Low organic matter reduces aggregate stability, decreases water holding capacity and undermines microbial communities that mediate nutrient cycling.

### 4.3 Compaction and structure loss

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Repeated heavy machinery traffic during wet seasons, puddling from surface irrigation, and loss of binding organic colloids lead to increased bulk density and reduced porosity—restricting root growth and reducing infiltration capacity, potentially reinforcing waterlogging in micro-depressions.

**4.4 Nutrient imbalances and biological activity**

Heavy reliance on mineral fertilization for high yields without balanced organic amendments can create nutrient imbalances (e.g., relative decline in soil P availability through fixation, reduced micronutrient availability), while lower SOC and microbial biomass reduce biological nutrient transformations (mineralization, nitrification) and biological disease suppression.

**5. Impacts on agricultural production**

**5.1 Crop yield responses**

Empirical relationships observed in irrigated arid systems indicate:

- Moderate salinity (EC ~1.5–2.5 dS $m^{-1}$) typically reduces sensitive crops' yields (vegetables) but many cereals and cotton tolerate moderate salinity with some yield loss.
- SOC decline correlates with lower available water storage and reduced drought resilience, penalizing yields in drier seasons.
- Compaction reduces rooting depth and nutrient uptake, diminishing potential yield despite adequate water and fertilizers.

In practical terms for the Middle Zarafshan, well managed plots (good drainage, SOC >1.0%, EC <2 dS $m^{-1}$) produce near-optimal yields for wheat (~3.0–4.0 t $ha^{-1}$ under local management) and cotton productivity comparable to regional averages; degraded plots experience yield drops of 20–50% depending on severity.

**5.2 Ecosystem services and long-term sustainability**

Soils with healthy structure and biological activity sustain decomposition, nutrient cycling, water infiltration and retention, and resilience to pests and drought—services essential to the oasis's long-term agricultural viability. Degraded soils erode these services, requiring greater fertilizer and water inputs and increasing vulnerability.

**6. Diagnostic indicators and monitoring**

A practical monitoring package for Middle Zarafshan irrigated soils should include:

1. **EC of saturation extract and SAR** — to track salinization and sodicity trends.
2. **Soil organic carbon (SOC) and active fractions (POC, microbial biomass C)** — to assess organic matter status.
3. **Bulk density and penetration resistance** — for structural condition.
4. **Basic fertility (available N, P, K) and pH**.
5. **Biological indicators** — e.g., dehydrogenase activity or enzymatic proxies, earthworm counts where applicable.
6. **Groundwater depth monitoring** — to identify rising water table risks.
7. **Remote sensing/GIS overlays** — to detect vegetation stress, surface salt crusts and areas with persistent waterlogging.

Regular (annual or biannual) monitoring allows early identification of hotspot areas and the prioritization of remediation.

**7. Management recommendations**

Based on the synthesis of regional knowledge and successful approaches in similar arid irrigated systems, the following integrated measures are recommended for the Middle Zarafshan:

**7.1 Water management and drainage**

- **Upgrade drainage infrastructure**: repair and extension of subsurface and surface drains to maintain groundwater table depths below critical thresholds (commonly >1.5–2.0 m from the soil surface for many crops).

- **Irrigation scheduling and efficiency**: adopt deficit irrigation where feasible, transition to more efficient systems (e.g., localized drip irrigation for orchards and vegetables) to reduce deep percolation and capillary rise.
- **Quality control of irrigation water**: monitor SAR and EC of canal water; where water quality is marginal, apply leaching fractions and amendments appropriately.

**7.2 Organic matter restoration**

- **Return crop residues** and encourage in-field composting to increase SOC.
- **Green manures and cover crops** in rotation (leguminous species) to build organic matter and biologically fix N.
- **Targeted application of compost or farmyard manure** (when available) on degraded plots to improve aggregation and microbial activity.

**7.3 Soil structure and compaction control**

- Reduce heavy machinery passes on wet soils; adopt controlled traffic farming.
- Implement minimum tillage or reduced tillage on suitable land to preserve structure and organic matter.

**7.4 Crop and rotation strategies**

- **Diversify cropping systems** to include legumes and deep-rooted species to improve soil structure and increase organic inputs.
- **Use salt-tolerant cultivars** on marginal plots to maintain production while remediation is underway.

**7.5 Biological amendments and phytoremediation**

- Application of mycorrhizal inoculants and beneficial soil bacteria (PGPR) can improve nutrient uptake and confer stress tolerance.
- Phytoremediation using halophytes or salt-accumulating plants on saline spots can help sequester and localize salts before removal or soil reclamation.

**7.6 Policy and extension**

- Strengthen farmer training and advisory services on integrated soil–water management.
- Establish incentives for adoption of efficient irrigation technologies and for practices that build SOC.
- Systematic mapping and prioritization of high-risk plots for reclamation funds.

**8. Conclusions**

Irrigated soils of the Middle Zarafshan oasis underpin local agricultural productivity but are increasingly exposed to degradation pressures—secondary salinization, organic matter decline, compaction and nutrient imbalance. Maintaining and enhancing soil health requires an integrated approach combining improved irrigation and drainage, organic matter restoration, conservation tillage, crop diversification, and active monitoring. Implementation of these measures will stabilize yields, reduce input demands over time, and preserve the oasis's role in regional food security.

**References**

Note: below are representative references useful for further reading; the user can request a full numbered reference list formatted for a specific journal style.

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