Soil Fertility, Soil Quality and Soil Health in Maharashtra: A Review

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Abstract

Maharashtra is one of India's most important agricultural states, with diverse agro-climatic zones ranging from high-rainfall Konkan to drought-prone Marathwada and Vidarbha. The state is dominated by Vertisols (deep black cotton soils) and associated Inceptisols and Entisols, supporting major crops such as cotton, soybean, sugarcane, pulses and cereals. Recent assessments indicate that soil fertility, soil quality and soil health in many parts of Maharashtra are under stress due to imbalanced fertilization, declining soil organic carbon (SOC), intensive tillage, residue removal and climate variability. Soil fertility studies in Latur, Beed, Nashik, Yavatmal and Khandesh regions report widespread deficiencies of available nitrogen and phosphorus, generally adequate to high potassium, emerging secondary nutrient (especially sulphur) limitations and serious micronutrient constraints, notably zinc and iron.In parallel, soil quality evaluations using soil quality indices (SQI) and SOC stock assessments in watersheds and micro-watersheds of Kolhapur, Morna and Khandesh highlight spatial variability in physical (bulk density, structure), chemical (pH, EC, nutrients) and biological properties across land uses and cropping systems. At the state level, Maharashtra has recently completed soil spectral mapping of its entire area, enabling village-level soil health information, while national Soil Health Card data show widespread N and organic carbon deficiencies in Indian soils, including Maharashtra.This review synthesizes available information on soil fertility status, soil quality assessment and soil health considerations in Maharashtra. It clarifies conceptual distinctions between soil fertility, quality and health, summarises key indicators and methodologies, and discusses major drivers of degradation. Finally, it outlines integrated management options—balanced nutrient use, organic matter management, conservation agriculture, biochar, and policy initiatives—that can enhance soil fertility and health for sustainable, climate-resilient agriculture in the state.

Keywords: Soil fertility, soil quality, soil health, Maharashtra, Vertisol, organic carbon, micronutrients, Soil Health Card, soil quality index

1. Introduction

Soil is the foundation of Maharashtra's agriculture and rural economy. The state covers diverse agro-ecological regions—high rainfall coastal Konkan, the Western Ghats, and large semi-arid to arid plateaus of Western Maharashtra, Marathwada and Vidarbha. This diversity is reflected in soil types, cropping patterns, and constraints.

Three related but distinct concepts are central:

- **Soil fertility** – the capacity of soil to supply essential nutrients in adequate amounts and suitable proportions for plant growth.
- **Soil quality** – the capacity of soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (multi-parameter concept, physical–chemical–biological).
- **Soil health** – a dynamic concept emphasizing living components of soil (microbial activity, biodiversity, organic matter), resilience and ecosystem services.

In Maharashtra, rapid intensification, expansion of irrigated agriculture, widespread use of high-analysis fertilizers, and climate stress have generated concerns about declining soil fertility and health, even as food and fibre demands continue to grow. This review focuses on the current status, drivers and management of soil fertility, soil quality and soil health in Maharashtra, based on published research, institutional reports, and recent state-level initiatives.

2. Soil Types and Agro-Ecological Setting of Maharashtra

Maharashtra's soils are largely derived from Deccan basalt and are dominated by shrink–swell clays (black soils), along with lighter-textured soils on uplands and alluvial plains. Soil survey and mapping work by ICAR–NBSS&LUP at various scales has characterized these soils by order, phase and capability classes.

2.1 Major soil orders

Table 1. Major soil orders and key characteristics in Maharashtra

Soil order	Common name	Typical areas / regions	Key features and constraints
Vertisols	Deep black cotton	Deccan plateau, much of Vidarbha, Marathwada, Western Maharashtra	High clay, high WHC, cracking, slow infiltration, poor drainage; prone to waterlogging, crusting; generally good K but low N & OC

Soil order	Common name	Typical areas / regions	Key features and constraints
Inceptisols	Medium black to brown	Transitional slopes, valley fills, parts of Marathwada, Khandesh	Moderate depth, moderate clay, variable fertility; emerging S & micronutrient issues
Entisols	Shallow/young soils	Hilly Konkan and Ghats, eroded uplands	Shallow, stony, erosion-prone; moisture stress; low nutrient reserves
Alfisols / others	Red and lateritic	Konkan, parts of Western Ghats	Acidic to neutral; P fixation, low base saturation in places

2.2 Cropping systems

- **Rainfed regions (large part of Vidarbha, Marathwada):** cotton, soybean, pigeonpea, sorghum, pearl millet, chickpea.
- **Irrigated belts (Western Maharashtra, sugar factories' command areas):** sugarcane, banana, vegetables, wheat, maize.
- **Horticulture:** grapes, pomegranate, citrus, mango, cashew, vegetables in various pockets.

Each combination of soil and cropping system generates unique soil fertility and quality challenges.

3. Status of Soil Fertility in Maharashtra

A large number of micro-watershed and tehsil-level studies have assessed the fertility status of Maharashtra's soils. Here we summarise key patterns for macro-, secondary and micronutrients.

3.1 Macronutrients (N, P, K)

Studies in Vertisols, Inceptisols and Entisols of Ausa tehsil (Latur district) found:

- Soils neutral to moderately alkaline, non-saline and low to medium in organic carbon.
- **Available N:** very low to low across soil orders.
- **Available P:** low to medium.
- **Available K:** moderately high to very high.

An assessment of agricultural lands under the jurisdiction of a sugar factory in Maharashtra reported:

- Low available N,
- Medium available P,
- High available K, indicating strong imbalance (high K relative to N and P).

These patterns—chronically low N, mostly low-to-medium P and generally adequate to high K—are repeatedly reported in Vertisols and associated soils across semi-arid Maharashtra.

3.2 Secondary nutrients (Ca, Mg, S)

A recent study on Inceptisols, Entisols and Vertisols in Manjra basin area of Latur tehsil reported:

- Soils neutral to moderately alkaline with safe EC and variable $CaCO_3$.
- Calcium and magnesium generally in medium to high categories.
- Sulphur status ranging from deficient to high, with nutrient index values indicating **medium Ca and Mg but high S** in some Inceptisols; however, localised S deficiencies are emerging, especially under intensive cropping and low organic inputs.

Other studies in scarcity-zone areas report S deficiency in a significant proportion of samples, linked to use of S-free fertilizers and removal of crop residues.

3.3 Micronutrients (Zn, Fe, Mn, Cu, B)

Micronutrient surveys in Washi tehsil (Osmanabad) showed:

- Variable but often adequate Fe and Mn,
- Widespread **zinc deficiency**,
- Local Cu and B issues.

Similarly, the sugar factory jurisdiction study reported that 69% of samples were deficient in Fe, nearly 3% in Mn and more than 65% in Zn, underlining the severity of micronutrient constraints in intensively cultivated systems.

3.4 Organic carbon

Soil organic carbon (SOC) is a central indicator of soil fertility and health. SOC stock assessments in Morna watershed and other parts of Maharashtra show:

- Higher SOC and lower bulk density under forest and perennial land uses;
- Lower SOC in cultivated and degraded lands, particularly under intensive tillage and residue removal.

National Soil Health Card–based assessments indicate that nearly half of Indian soils are low in organic carbon and about 64% are N-deficient, reflecting large-scale depletion of soil organic matter and N reserves, a pattern that holds for many districts in Maharashtra as well.

4. Soil Quality and Soil Health: Concepts and Maharashtra Evidence

4.1 Conceptual distinctions

- **Soil fertility** is primarily about nutrient-supplying capacity.
- **Soil quality** integrates chemical, physical and biological attributes and links them to soil functions such as biomass production, water regulation and environmental buffering.
- **Soil health** emphasizes the living ecosystem—microbial biomass, biodiversity, organic matter dynamics, resilience and self-regulation.

While SOC and nutrient status are widely used proxies, recent work stresses that SOC alone does not fully capture soil health; microbial and biochemical indicators must complement chemical data.

4.2 Soil quality assessments in Maharashtra

Several studies have used minimum data sets (MDS) and soil quality index (SQI) approaches in Maharashtra:

- **Khandesh region (Jalgaon, Dhule, Nandurbar):** evaluation of cultivated soil quality showed spatial variability in pH, EC, OC, macro and micronutrients, indicating areas of moderate to poor soil quality needing targeted interventions.
- **Shegaon watershed, Chandrapur district:** soil quality assessment and mapping highlighted the role of landform and land use on SQI, with degraded uplands showing lower scores and valley bottoms/irrigated lands showing relatively better quality but sometimes higher salinity risk.
- **Nilona micro-watershed, Yavatmal (cotton-growing environs):** development of SQI using physical and chemical indicators identified bulk density, SOC, available N and Zn as key drivers of soil quality for cotton.
- **Baglan tahsil, Nashik:** recent work on soil quality assessment reported wide variability in primary nutrients and micronutrients across villages, with implications for site-specific nutrient management.

These studies collectively show that soil quality in Maharashtra is highly heterogeneous and strongly influenced by land use, management intensity, and terrain.

5. Drivers of Soil Degradation and Health Decline

Major drivers affecting soil fertility, quality and health in Maharashtra include:

1. **Imbalanced fertilizer use**
   - Excessive reliance on N and P fertilizers with limited use of K and little attention to S and micronutrients in some systems, and the opposite pattern (excess K) in others such as sugarcane belts.
2. **Declining organic matter**
   - Reduced application of farmyard manure (FYM), removal or burning of crop residues, limited green manuring and low biomass returns to soil contribute to reduced SOC and N reserves.
3. **Intensive tillage and erosion**
   - Continuous deep tillage in Vertisols and shallow, erosion-prone Entisols/Alfisols accelerates loss of fine particles and organic matter; hilly areas in Western Ghats and Konkan are especially vulnerable to erosion.
4. **Poor irrigation water quality and salinity**
   - Localised salinity and sodicity problems emerge under canal and groundwater irrigation in low-lying Vertisols, especially with poor drainage.
5. **Pollution and unregulated land use**
   - In tourism hubs like Matheran, high horse traffic and poor waste management have caused air, water and **soil contamination**, with elevated salinity, organic load and nutrient imbalances in soils.
6. **Climate variability**
   - Recurrent droughts in Marathwada and Vidarbha interact with soil constraints (low SOC, poor structure) to reduce water-holding capacity, exacerbating crop failures and land degradation.

6. Indicators and Assessment Approaches

6.1 Chemical indicators

- pH, EC, $CaCO_3$
- Organic carbon
- Available N, P, K
- Secondary nutrients (Ca, Mg, S)
- DTPA-extractable micronutrients (Zn, Fe, Mn, Cu)

These parameters are routinely measured in soil testing laboratories and underpin the Soil Health Card scheme.

Table 2. General pattern of fertility status in many cultivated Vertisols/Inceptisols of Maharashtra
(Based on multiple district-level studies)

Parameter	Typical status	Common issues
pH	Neutral–alkaline	Calcareous patches, P fixation
EC	Non-saline	Local salinity under poor drainage
Organic carbon	Low–medium	Declining trend, low biomass return

Parameter	Typical status	Common issues
Available N	Low	Chronic deficiency
Available P	Low–medium	Inefficient use, fixation in some soils
Available K	Medium–high	Imbalance with N and P
Sulphur	Variable	Emerging deficiency in some areas
Zn	Often low	Major micronutrient constraint
Fe, Mn	Variable	Fe deficiency in some irrigated belts

6.2 Physical indicators
- Bulk density, porosity and penetration resistance
- Aggregate stability, structure and crusting
- Infiltration rate and hydraulic conductivity
- Available water-holding capacity

SOC stock and bulk density mapping in Kolhapur district and Morna watershed show clear relations between physical quality and land use: lower bulk density and better structure under forests/perennials and higher compaction under intensive cultivation.

6.3 Biological indicators
- Microbial biomass C and N
- Soil respiration and enzymatic activities
- Earthworm numbers and biodiversity indicators

Although less frequently measured in routine soil testing, these are increasingly recognized as essential components of soil health monitoring.

6.4 Mapping and decision-support tools

ICAR–NBSS&LUP and state agencies have developed soil resource maps, atlases and digital tools such as the **BHOOMI Geoportal** and a state-wide soil spectral library, making Maharashtra the first state in India to map its entire soil at such detail. These tools enable village-level soil health assessment and support precision nutrient management.

7. Management Strategies to Improve Soil Fertility, Quality and Health

7.1 Balanced and site-specific nutrient management
- Use soil test–based fertilizer recommendations for N, P, K, S and micronutrients.
- Promote **site-specific nutrient management (SSNM)** integrating soil test data, crop demand and yield targets.
- Correct chronic N and P deficiency while maintaining K balance; apply S (e.g. gypsum, SSP) and Zn ($ZnSO_4$) where deficient.

7.2 Organic matter management and SOC enhancement
- Regular application of FYM, compost and farm-based manures.
- Green manuring with sunnhemp, dhaincha or green gram in fallows.
- Retention and incorporation of crop residues instead of burning.

Recent initiatives in Maharashtra emphasise **biochar** made from crop residues to increase SOC, improve water retention and nutrient use efficiency; field experiences indicate improved sugarcane yields when SOC is raised.

7.3 Conservation agriculture and erosion control
- Reduced or zero tillage with residue retention in Vertisol-based systems (soybean–wheat, cotton-based systems).
- Contour farming, graded bunds, vegetative barriers and cover crops on slopes to reduce erosion in Konkan and Ghats.

7.4 Water management and salinity control
- Adoption of micro-irrigation (drip, sprinkler) to reduce waterlogging and salinity.
- Conjunctive use of different water sources and regular monitoring of irrigation water quality.
- Drainage improvement in low-lying Vertisols and sugarcane belts.

7.5 Biological inputs and soil biodiversity
- Use of biofertilizers (Rhizobium, Azotobacter, PSB, KSB) and PGPR to improve nutrient availability and root growth.
- Integration with organic amendments to provide energy substrate for microbes.

Figure 2 (suggested): *Integrated soil fertility and soil health management model combining balanced fertilizers, organics, biochar, conservation tillage, diversified rotations and micro-irrigation for a typical Vertisol-based cotton/soybean–wheat system in Maharashtra.*

8. Policy and Institutional Initiatives in Maharashtra

Key initiatives influencing soil health in Maharashtra include:

1. **Soil Health Card Scheme (SHC)**
   - Provides farmers with soil test–based nutrient recommendations.
   - National analyses of SHC data highlight the scale of N and OC deficiency and the need to broaden indicators beyond simple chemical parameters.
2. **ICAR–NBSS&LUP and BHOOMI Geoportal**
   - Detailed soil resource mapping and soil health information, with spectral library–based rapid diagnostics.
3. **State schemes on micro-irrigation and organic farming**
   - Support for drip/sprinkler in horticulture and sugarcane; promotion of organic inputs and recycling of agro-industrial wastes (press mud, distillery effluent after treatment) where safe.
4. **Awareness and capacity building**
   - Workshops on biochar, organic carbon management and mechanisation led by policymakers and scientists encouraging farmers to adopt soil health–enhancing practices.

9. Research Gaps and Future Priorities

Despite substantial work, several gaps remain:

- **Integration of biological indicators** into routine soil health monitoring in Maharashtra's soil testing laboratories.
- Long-term experiments on **conservation agriculture**, residue retention and diversified crop rotations under Vertisol and Inceptisol systems.
- High-resolution **SOC stock assessment** and monitoring to support climate-smart agriculture and carbon sequestration goals.
- Quantification of cumulative impacts of agro-industrial effluents, urban wastes and tourism on soil health in sensitive zones (e.g., around hill stations and peri-urban belts).
- Development of **decision-support tools** that combine soil maps, SHC data and remote sensing for field-level nutrient management.

10. Conclusion

Maharashtra's soils, particularly the extensive Vertisols and associated Inceptisols and Entisols, are highly productive yet increasingly vulnerable. The evidence shows a consistent pattern of low N and organic carbon, low-to-medium P, generally adequate K, emerging S deficiencies and widespread Zn (and sometimes Fe) deficiencies. Physical degradation through compaction and erosion, together with declining biological activity, threatens long-term soil health. At the same time, the state has taken pioneering steps in soil mapping and digital soil information, offering a strong platform for targeted interventions.

Sustainably managing these soils demands a paradigm shift from purely yield-driven, fertilizer-centric approaches towards **integrated soil fertility and health management**: balanced and site-specific nutrient supply; restoration of SOC through organics, residues and biochar; conservation agriculture; improved water management; and inclusion of biological indicators in monitoring. If these strategies are systematically scaled up through policy support, extension and farmer participation, Maharashtra can restore and enhance soil fertility, improve soil quality and safeguard soil health for future generations of farmers and consumers.

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