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Review Article

Exploring the relationship between soil moisture dynamics and postharvest losses in drought and flood-prone regions of the tropics: A review

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ABSTRACT

Soil moisture dynamics significantly influence agricultural productivity and postharvest losses, particularly in tropical regions prone to droughts and floods. Extreme moisture conditions negatively impact crop quality, storage potential, and food security, with droughts causing poor grain filling, increased pest infestations, and inefficient drying, while floods result in waterlogging, delayed harvesting, and contamination risks. This review explores the relationship between soil moisture variability and postharvest losses, highlighting the need for sustainable soil and water management strategies. Conservation agriculture, improved drainage systems, and postharvest technologies such as solar drying, hermetic storage, and AI-driven monitoring systems are critical in mitigating losses. Despite advancements, knowledge gaps remain in predictive modeling, localized soil moisture retention, and cost-effective postharvest solutions for smallholder farmers. Future research should focus on Artificial Intelligence-driven soil moisture forecasting, adaptive irrigation techniques, and resilient storage infrastructure. Additionally, policy frameworks must integrate climate adaptation strategies, research funding, and extension services to enhance farmer capacity. A multi-disciplinary approach involving governments, research institutions, and local communities is essential for implementing sustainable solutions. The integration of remote sensing, Geographic Information System (GIS), and AI technologies can improve real-time monitoring and decision-making in soil moisture management. Strengthening collaborations and investments in climate-smart agriculture will enhance food security and economic stability in tropical regions. This review highlights the pressing need for innovative, scalable, and region-specific interventions to mitigate postharvest losses resulting from soil moisture extremes.

KEYWORDS: *Adaptation, AI-driven monitoring, Climate, Remote sensing, Storage*

INTRODUCTION

Soil moisture plays a crucial role in sustaining agricultural productivity, particularly in tropical regions where rainfall patterns are often unpredictable (Lamptey, 2022). It influences plant growth, nutrient availability, microbial activity, and overall soil health. In tropical climates, characterized by alternating wet and dry seasons, soil moisture dynamics are highly variable, affecting both crop yields and postharvest management (Abhishek, 2023). Excessive soil moisture, often due to heavy rainfall and flooding, can lead to waterlogging and root rot, while prolonged dry spells cause soil desiccation, reducing crop resilience and productivity (Kumar et al., 2022).

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Efficient soil moisture management is therefore essential for ensuring sustainable food production in these regions (Sabir et al., 2024).

Postharvest losses (PHL) refer to the reduction in quantity and quality of agricultural produce between harvest and consumption (Bendinelli et al., 2020). These losses occur due to improper handling, inadequate storage, pest infestations, and unfavorable environmental conditions (Shahbazi et al., 2025). In the tropics, high humidity levels accelerate spoilage, while extreme dryness can lead to shrinkage and brittleness in stored crops. The economic implications of PHL are significant, as they reduce farmers' income and limit food availability in both rural and urban areas (Sheahan & Barrett, 2017). Moreover, postharvest losses contribute to food insecurity by diminishing the volume of marketable produce, exacerbating malnutrition, and increasing the burden on already strained food supply chains (Barrett et al., 2022).

Tropical regions, particularly in Africa, South Asia, and parts of Latin America, are prone to extreme climatic events such as prolonged droughts and intense floods (Vinke et al., 2017). These environmental challenges directly impact soil moisture availability and postharvest management. In drought-prone areas, crops often suffer from insufficient soil moisture, leading to poor grain filling, reduced storage quality, and vulnerability to pest attacks (Ghazala, 2024). Conversely, flood-prone regions experience excessive moisture, which fosters fungal growth, contamination, and spoilage of harvested produce (Rahman, 2021). Smallholder farmers, who form the backbone of tropical agriculture, often lack the resources and infrastructure to mitigate these challenges effectively (Urugo et al., 2024).

This review explores the relationship between soil moisture dynamics and postharvest losses in drought and flood-prone tropical regions. It examines how soil moisture extremes influence postharvest handling, storage, and preservation techniques. Furthermore, it discusses sustainable soil and water management practices, postharvest technologies, and the role of emerging innovations such as AI and remote sensing in mitigating losses. By analyzing case studies and policy interventions, this review aims to provide actionable insights for researchers, policymakers, and farmers to enhance agricultural resilience in tropical environments.

SOIL MOISTURE DYNAMICS: CONCEPTS AND INFLUENCING FACTORS

i. Definition and Components of Soil Moisture

Soil moisture refers to the amount of water retained in the soil, which is essential for plant growth, microbial activity, and soil chemical processes (Gavrilescu, 2021). In tropical environments, soil moisture fluctuates due to intense rainfall during wet seasons and extended dry periods in drought-prone regions (Eslamian et al., 2018). The key components of soil moisture include: Field Capacity (FC): The maximum amount of water the soil can hold after excess water has drained, providing sufficient moisture for plant uptake (Tumer, 2019). In tropical regions, soils with high clay content tend to retain water longer, whereas sandy soils drain quickly (Osman & Osman, 2018). Wilting Point (WP): The minimum soil moisture level at which plants can no longer extract water, leading to wilting and potential crop failure (Tumer, 2019). This is a major concern in drought-prone areas where soil moisture drops below this threshold for extended periods. Available Water Capacity (AWC): The difference between field capacity and wilting point, indicating the moisture available for plant uptake (Arslan et al., 2014). In tropical climates, maintaining adequate AWC is crucial for sustaining crop productivity during dry spells. Saturation: When soil pores are filled with water, it often occurs in flood-prone tropical regions, leading to oxygen deficiency in plant roots and increased risks of soil degradation (Aslam et al., 2023).

ii. Factors Affecting Soil Moisture in Tropical Environments

Several factors influence soil moisture availability and distribution in tropical regions, including: Climate and Rainfall Patterns: Tropical regions experience high rainfall variability, with alternating wet and dry seasons (Nicholson, 2017). In flood-prone areas, intense rainfall leads to waterlogging, reducing soil aeration and increasing postharvest spoilage risks (Gogoi et al., 2024). In drought-prone zones, erratic rainfall and prolonged dry periods cause moisture deficits, making crops more susceptible to failure (Begna, 2022). Soil Texture and Structure: Sandy soils, common in tropical savannas, have low water-holding capacity, leading to rapid drainage and frequent drought stress (Naorem et al., 2023). Clayey soils, prevalent in humid tropics, retain moisture longer but are prone to waterlogging during heavy rains. Loamy soils, found in many tropical agricultural zones, offer a balanced water-holding capacity, making them ideal for farming (Osman, 2018).

Land Use and Vegetation Cover: Deforestation and land degradation in tropical areas reduce soil organic matter, decreasing moisture retention (Amoakwah et al., 2022). Agricultural practices such as monocropping and overgrazing can lead to soil compaction, reducing water infiltration and availability, while conservation practices like agroforestry and cover cropping help improve soil structure and moisture retention (Kumar & Pandey, 2024). Irrigation and Water Management Practices: In tropical regions, irrigation is often necessary to supplement rainfall, especially in dryland farming systems (Amede et al., 2014). Traditional surface irrigation methods can lead to water losses through evaporation and runoff, whereas drip irrigation and rainwater harvesting improve soil moisture efficiency (Zhang et al., 2021). Poor drainage systems in flood-prone regions contribute to prolonged water stagnation, affecting soil aeration and crop survival (Rupngam & Messiga, 2024).

iii. Seasonal and Regional Variations in Soil Moisture in Drought- and Flood-Prone Regions

Soil moisture distribution varies significantly across tropical landscapes due to differences in climate, topography, and land use (Zuo et al., 2025). Drought-Prone Regions: Examples include the Sahel region of Africa and parts of northeastern Brazil (Yobom, 2020). These areas experience low annual rainfall, leading to chronic soil moisture deficits. Sustainable water management techniques, such as mulching, water conservation farming, and soil moisture sensors, are crucial for maintaining productivity (Tiwari et al., 2023). Flood-Prone Regions: Examples include the Niger Delta, Bangladesh, and coastal Southeast Asia (Husain & Sharma, 2022). These areas receive heavy seasonal rainfall, causing frequent waterlogging and soil erosion. Effective drainage systems, flood-resistant crop varieties, and raised-bed farming are key strategies to mitigate soil moisture excess (Singh et al., 2022). Seasonal Variations: The rainy season typically results in high soil moisture levels, which can be beneficial for crops but also increase the risks of fungal infections and postharvest losses (Bradford et al., 2020). The dry season leads to reduced soil moisture availability, requiring adaptive measures such as supplemental irrigation, mulching, and conservation tillage (Demo & Asafe Bogale, 2024).

Impacts of Soil Moisture Extremes on Postharvest Losses

Soil moisture extremes - either excessive dryness or prolonged water saturation—pose significant challenges to postharvest management, especially in tropical regions where climatic variability is high (Garg et al., 2024). Both drought and flood conditions influence crop quality, storage potential, and postharvest handling, leading to considerable food losses and economic setbacks for farmers (Binge et al., 2023).

Table 1: Effects of Soil Moisture Extremes on Postharvest Losses in Tropical Regions

Soil Moisture Condition	Effects on Crops	Impact on Postharvest Losses
Drought	Poor grain filling, reduced yield	Increased susceptibility to pests, poor storage quality, and difficulty in drying
Drought	Wilting and premature maturation	Reduced market value, lower processing quality
Flooding	Waterlogging, delayed harvest	Increased spoilage, fungal and bacterial contamination
Flooding	Excess moisture in stored crops	Mold growth, mycotoxin contamination, postharvest diseases

Source: Bradford et al. (2020)

i. Drought-Induced Postharvest Losses

Drought-prone tropical regions, such as the Sahel in Africa and parts of northern Brazil, often experience prolonged dry spells that negatively impact crop production and postharvest processes (Ariom et al., 2022; Garg et al., 2024). The primary effects include: Effects of Water Stress on Crop Quality and Storage Potential: Insufficient soil moisture reduces crop vigor, leading to poor grain and fruit development. In cereals such as maize, sorghum, and rice, drought stress results in lightweight grains with lower starch content, reducing milling quality and market value (Anjali et al., 2023). Fruits and vegetables grown under drought conditions tend to develop tougher skins and lower moisture content, affecting texture and shelf life (Adewoyin, 2023). This makes them more prone to mechanical damage during handling and storage. Reduced moisture levels in crops can also lead to nutrient imbalances, such as low protein content in legumes, further affecting their nutritional value and storage stability (Sarkar et al., 2021).

Reduced Grain Filling and Susceptibility to Pest Infestations: Drought stress often leads to incomplete grain filling in crops like maize, millet, and rice, resulting in shriveled and underdeveloped kernels (Debesa et al., 2023). These poorly formed grains are more susceptible to storage pests such as weevils and borers, which thrive in dry conditions (Demis & Yenewa, 2022). Low moisture levels in grains can cause micro-cracks, making them more vulnerable to fungal infections, particularly *Aspergillus* species, which produce aflatoxins—a major concern in tropical storage systems (Majzoobi et al., 2023). Impact on Drying and Preservation Processes: In tropical regions, postharvest drying is crucial to prevent microbial growth. However, drought conditions can lead to uneven drying, especially in sun-dried crops, resulting in moisture variation within stored produce (Deng et al., 2021). Traditional drying methods, such as open-air drying, become less effective as extreme heat can cause rapid moisture loss in the outer layers while inner portions remain damp, increasing the risk of mold formation during storage (Inyang et al., 2017). The scarcity of water in drought-affected areas also limits the use of effective postharvest preservation techniques, such as hydro-cooling for fruits and vegetables, further reducing shelf life (Ray et al., 2020).

ii. Flood-Induced Postharvest Losses

Tropical flood-prone regions, such as the Niger Delta in Nigeria and the Mekong Delta in Southeast Asia, experience heavy seasonal rainfall that leads to excessive soil moisture and postharvest complications (Joint FAO, 2018). Key impacts include: Waterlogging Effects on Crop Yield and Contamination Risks (Molds, Toxins): Waterlogging, caused by prolonged soil saturation, restricts oxygen availability to plant roots, leading to reduced yield and poor-quality produce (Rathod & Verma, 2023). Crops such as cassava and yams suffer from tuber rot when exposed to excessive moisture. Excess soil moisture increases the risk of fungal and bacterial contamination, particularly in grains and legumes (Mengistu, 2022). Flooded rice fields, for example, often experience high levels of fungal infections like *Fusarium* and *Penicillium*, which produce harmful toxins (Kiran et al., 2021). High humidity during storage in flood-affected regions promotes the growth of *Aspergillus* fungi, leading to aflatoxin contamination in maize, groundnuts, and other staples (Surekha et al., 2018). The bar chart (Figure 1) compares postharvest loss factors in drought-prone and flood-prone regions. It shows that moisture-related spoilage is more prevalent in flood-prone areas, while pest infestations are a major issue in drought-prone regions.

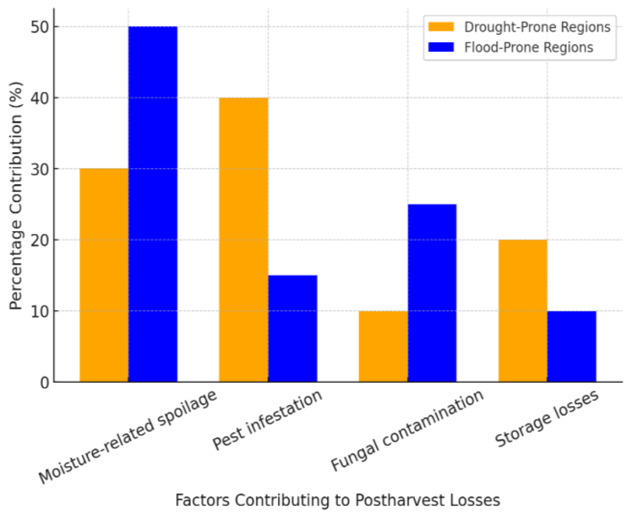

Figure 1: Post-harvest loss factors in drought vs. flood-prone regions (Kourgialas, 2021)

Delays in Harvest Leading to Spoilage: Heavy rains and floods often make fields inaccessible, delaying harvest and exposing crops to further deterioration (Bhadwal et al., 2017). Fruits such as bananas, mangoes, and tomatoes ripen prematurely under excessive moisture conditions, leading to rapid spoilage. In rice and wheat, delayed harvest due to waterlogging causes pre-harvest sprouting, significantly reducing milling quality and storage longevity (Mamrutha et al., 2022). Waterlogged soils hinder the mechanized harvesting of root crops like cassava and yams, forcing manual labor, which is slower and increases the risk of postharvest losses (Veena et al., 2021). Increased Vulnerability to Fungal and Bacterial Infections in Stored Produce: Flood-induced high humidity creates ideal conditions for postharvest diseases such as *Phytophthora* in fruits and *Rhizopus* rot in stored vegetables (Aslam et al., 2024). In improperly dried grains, residual moisture from flood conditions accelerates mold growth, increasing the likelihood of spoilage and mycotoxin contamination (Alegbeleye et al., 2022). Poor drainage and lack of proper storage infrastructure in tropical flood-prone areas exacerbate the problem, leading to widespread grain spoilage, reduced food quality, and significant economic losses (Rahman, 2021).

ROLE OF SOIL AND WATER MANAGEMENT IN MITIGATING POSTHARVEST LOSSES

Effective soil and water management is crucial for reducing postharvest losses in tropical regions, where moisture extremes pose significant challenges (Gunny et al., 2021). Implementing sustainable soil moisture management strategies and adopting appropriate postharvest technologies can help farmers preserve crop quality, minimize spoilage, and improve food security (Bradford et al., 2020).

Table 2: Soil and Water Management Strategies for Mitigating Postharvest Losses

Strategy	Application	Benefit
Conservation agriculture (mulching, cover crops)	Retains soil moisture during drought	Enhances water availability, reduces soil erosion
Drainage systems (raised beds, canals)	Prevents waterlogging in flood-prone areas	Reduces moisture-related spoilage and contamination
Rainwater harvesting	Captures and stores water for dry periods	Provides supplementary irrigation during droughts
Solar and mechanical drying	Postharvest moisture control	Improves shelf life, prevents mold growth
Hermetic storage	Airtight grain storage	Reduces postharvest losses due to pests and moisture

Source: Singh et al. (2022)

I. Sustainable Soil Moisture Management Strategies

Managing soil moisture efficiently is essential for stabilizing agricultural productivity and reducing postharvest losses (Neme et al., 2021). Approaches that can help mitigate the effects of both drought and excessive moisture in tropical environments include: Conservation Agriculture and Soil Moisture Retention Techniques. Mulching: Organic mulches (e.g., crop residues, leaves) and synthetic mulches help retain soil moisture during dry periods and prevent excessive evaporation (Demo & Asafe Bogale, 2024). This technique is widely used in tropical regions to protect crops from heat stress. Cover Cropping: Planting cover crops such as legumes improves soil structure, enhances moisture retention, and reduces erosion, particularly in drought-prone tropical areas (Garg et al., 2024). Minimum Tillage: Reducing soil disturbance conserves soil moisture and maintains organic matter, making crops more resilient to moisture stress. This is particularly useful in rain-fed agricultural systems (Lamptey, 2022). Terracing and Contour Farming: In hilly tropical regions, terracing and contour farming slow water runoff, improve infiltration, and prevent soil erosion, thus maintaining optimal soil moisture for crops (Amankwaa et al., 2024). Biochar and Organic Amendments: Adding biochar and compost to soils enhances water retention capacity, improving resilience to drought conditions (Vedere et al., 2023). The line graph (Figure 2) illustrates seasonal soil moisture variations in a tropical environment. Soil moisture levels peak during the wet season (June–September) and drop significantly in the dry season (November–April), highlighting the challenges of moisture management in tropical agriculture.

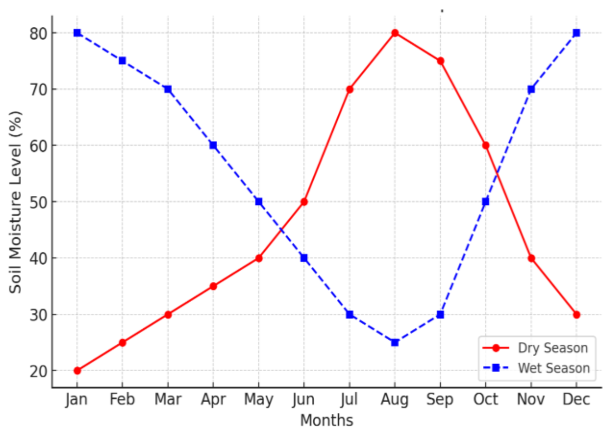

Figure 2. Seasonal Soil Moisture Variation in a Tropical Environment (Cusack et al., 2019)

ii. Drainage Systems and Water Management in Flood-Prone Regions

Raised Bed Farming: Elevating planting beds reduces waterlogging in flood-prone tropical areas, ensuring better root aeration and reducing crop losses (Pandey et al., 2021). Improved Drainage Channels: Constructing drainage ditches, canals, and raised field borders helps divert excess water away from farmlands, preventing prolonged soil saturation (Valipour et al., 2020). Agroforestry and Vegetative Buffer Strips: Planting trees and grasses along field boundaries helps regulate water movement, reduces soil erosion, and improves soil structure (Cole et al., 2020). Rainwater Harvesting and Storage: In flood-prone areas, excess water can be collected in reservoirs for later use during dry periods, balancing soil moisture levels throughout the year (Desta et al., 2024).

iii. Postharvest Technologies for Moisture-Stressed Environments

Beyond soil and water management, effective postharvest technologies are essential to preserving crop quality and reducing losses in moisture-stressed tropical regions (Saha et al., 2021). Drying Techniques (Solar Drying, Mechanical Drying): Solar Drying: A cost-effective method widely used in tropical climates where sunshine is abundant. Solar dryers protect crops from contamination while ensuring controlled drying, reducing aflatoxin risks in grains and nuts (Ayeni et al., 2021). The Nigerian Stored Products Research Institute (NSPRI) has developed a Parabolic Shaped Solar Dryer (PSSD) designed to harness solar energy for efficient and hygienic drying of agricultural produce (Ade et al., 2018; Kamaldeen & Okedokun, 2022; Kazeem et al., 2024). Collaborative research between the National Open University of Nigeria (NOUN) and NSPRI has been proposed for PSSD improvement in terms of energy efficiency, drying time, adaptability to different types of agricultural produce, and cost-benefit analysis to enhance adoption. Mechanical Drying: Technologies such as rotary dryers and forced-air drying systems help achieve uniform moisture reduction, particularly for high-value crops like coffee, cocoa, and rice in humid tropical environments (Gorijan et al., 2022). Improved Open-Air Drying Practices: Where advanced drying technologies are unavailable, simple improvements such as drying platforms, tarpaulins, and raised racks can minimize contamination from soil moisture and pests (Shrestha, 2017). The pie chart in Figure 3 illustrates the contribution of different factors to postharvest losses in tropical regions. Moisture-related spoilage accounts for the highest percentage (35%), followed by pest infestations (25%), while inadequate storage and fungal contamination each contribute 20%.

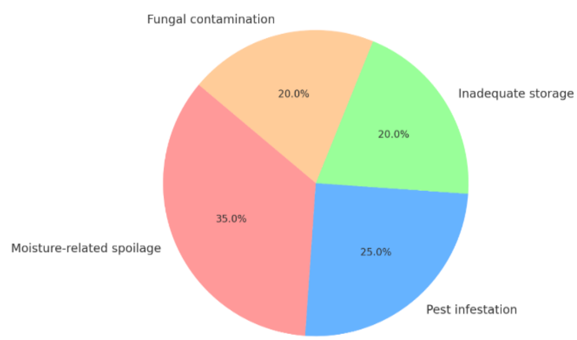

Figure 3: Contributions of Different Factors to Postharvest Losses in Tropical Regions (Obayelu et al., 2021)

iv. Improved Storage Systems (Hermetic Storage, Controlled Atmosphere)

Hermetic Storage Bags: Airtight storage solutions like Purdue Improved Crop Storage (PICS) bags prevent moisture infiltration and protect grains from pests and fungal contamination in humid tropical conditions (Kobia, 2022). Controlled Atmosphere Storage: By regulating oxygen and carbon dioxide levels, this method slows down spoilage and extends the shelf life of perishables like fruits and vegetables (De Corato, 2020). Elevated and Well-Ventilated Storage Structures: In flood-prone areas, grain storage on raised platforms or in well-ventilated cribs helps reduce exposure to excess moisture and prevents fungal growth (Colli et al., 2023). Use of Desiccants and Moisture Absorbers: In humid environments, desiccants like silica gel or charcoal-based moisture absorbers help maintain low humidity in storage facilities, reducing spoilage (Matthew et al., 2019).

v. Processing Innovations to Enhance Shelf Life

Fermentation and Drying Techniques: Traditional processing methods, such as fermenting cassava into garri or drying plantains into flour, reduce moisture content, making crops more stable for long-term storage (Anyiam et al., 2020). Value Addition through Processing: Converting fresh produce into processed goods (e.g., dried fruits, canned vegetables, powdered spices) reduces dependency on fresh storage and minimizes postharvest losses (Das & Sharangi, 2018). Cold Storage and Refrigeration: While energy constraints limit widespread refrigeration in rural tropical areas, the use of solar-powered cold storage and evaporative cooling chambers helps preserve perishables (Garcia et al., 2024).

APPLICATION OF AI AND REMOTE SENSING IN MONITORING SOIL MOISTURE AND POSTHARVEST LOSSES

The integration of artificial intelligence (AI) and remote sensing technologies is transforming agricultural practices in tropical regions by enabling real-time monitoring of soil moisture and early detection of postharvest losses (Mmbando, 2025). These technologies provide crucial insights into soil conditions, predict the impact of extreme weather events, and optimize storage and processing strategies, ultimately improving food security and reducing economic losses for farmers (Obasi et al., 2024; Pandey & Mishra, 2024; Getahun et al., 2024).

i. Use of Remote Sensing and GIS for Soil Moisture Mapping

Remote sensing and Geographic Information Systems (GIS) have become essential tools for assessing soil moisture variations across tropical landscapes, where unpredictable rainfall patterns and high evapotranspiration rates pose significant challenges (Obasi et al., 2024). Satellite-Based Soil Moisture Mapping: Satellites such as Sentinel-1, SMAP (Soil Moisture Active Passive), and MODIS (Moderate Resolution Imaging Spectroradiometer) provide large-scale soil moisture data using microwave and thermal imaging techniques (Babaeian et al., 2019). These datasets help identify drought- and flood-prone areas, allowing for better agricultural planning. Drone-Assisted Soil Monitoring: In regions with fragmented farmlands, drones equipped with multispectral and infrared sensors can provide high-resolution soil moisture maps (Jorica et al., 2022). This technology is particularly useful for precision agriculture in tropical environments where localized variations in soil moisture affect crop productivity (Mendes et al., 2020). GIS-Based Decision Support Systems: GIS platforms integrate remote sensing data with field measurements, enabling policymakers and farmers to visualize soil moisture trends, optimize irrigation schedules, and plan postharvest handling based on predicted environmental conditions (Kumar & Sharma, 2024).

Table 4: Role of AI and Remote Sensing in Soil Moisture and Postharvest Management

Technology	Application Area	Benefits
Remote sensing (satellite imagery, GIS)	Soil moisture monitoring	Provides real-time moisture data, aids decision-making
AI-driven predictive models	Drought and flood forecasting	Improves early warning systems for farmers
Smart sensors (IoT-based)	Soil and storage environment monitoring	Reduces moisture-related losses, enhances storage efficiency
Automated drying systems	Optimized drying process	Minimizes spoilage, maintains product quality

Source: Mallik et al. (2025)

ii. AI-Driven Predictive Models for Drought and Flood Impact Assessments

AI models enhance agricultural resilience in tropical regions by analyzing vast datasets and predicting extreme weather events that could impact soil moisture levels and postharvest losses (Kumari & Muthulaskmi, 2024; Mmbando, 2024). Machine Learning for Drought Prediction: AI algorithms, trained on historical climate, soil, and crop data, can predict drought occurrences with high accuracy (Mokhtar et al., 2021). These models help farmers adjust planting dates, select drought-resistant crop varieties, and implement water conservation strategies (Towolawi et al., 2024). Flood Risk Assessment Using AI: In flood-prone tropical regions, AI models analyze rainfall patterns, river discharge rates, and topographical data to forecast flooding events (Trong et al., 2023). This allows for early harvesting decisions and relocation of stored produce to safer areas. Crop Health Monitoring and Yield Forecasting: AI-powered platforms such as Google Earth Engine and IBM Watson analyze satellite imagery and weather data to predict crop stress due to moisture extremes. This helps in planning harvest and postharvest storage strategies (Ramteke & Kshirsagar, 2023).

iii. Smart Postharvest Monitoring Technologies

AI-driven monitoring systems are revolutionizing postharvest management in tropical regions by reducing spoilage, improving storage efficiency, and enhancing food safety (Das et al., 2025). IoT-Based Storage Sensors: Internet of Things (IoT) sensors placed in grain silos and storage facilities monitor humidity, temperature, and gas composition in real-time (Ekuewa et al., 2022). These sensors alert farmers to potential mold growth, insect infestations, or moisture imbalances, preventing large-scale postharvest losses (Aarif et al., 2025).

AI-Powered Sorting and Grading Systems: Advanced image recognition technologies, integrated with AI, assess the quality of harvested produce and classify them based on moisture content, size, and presence of defects (Singh et al., 2022). This improves market value and minimizes waste. Automated Drying Systems: AI-driven solar and mechanical drying systems adjust drying times based on real-time weather and crop moisture levels, ensuring optimal drying conditions and reducing aflatoxin contamination in grains and nuts (Raghavan & Kurian, 2024). Blockchain for Supply Chain Transparency: In tropical regions, blockchain technology is increasingly used to track and verify the quality and moisture status of agricultural products from farm to market, reducing fraud and postharvest inefficiencies (Gideon, 2024).

CASE STUDIES AND REGIONAL PERSPECTIVES

The impacts of soil moisture extremes on postharvest losses vary across different tropical regions, particularly in drought- and flood-prone areas (Akinkuolie et al., 2025). Examining case studies from these regions provides insights into the challenges faced by farmers and the effectiveness of various soil moisture management strategies in mitigating postharvest losses (Gunny et al., 2024). This section highlights selected case studies and key lessons learned from tropical environments, focusing on Sub-Saharan Africa and South Asia.

i. Drought-Prone Regions: Sub-Saharan Africa (Sahel Region)

The Sahel region of Sub-Saharan Africa, stretching across countries such as Niger, Mali, and Chad, is characterized by low and highly variable rainfall, leading to frequent droughts that severely impact crop production and postharvest storage (Mirzabaev et al., 2021; Clearinghouse, 2021). Challenges include: Erratic rainfall and prolonged dry spells reduce soil moisture, affecting crop yield and grain filling. Poor postharvest drying conditions lead to high aflatoxin contamination in stored grains (Neme & Muhammed, 2017). Lack of efficient storage facilities results in postharvest losses exceeding 30% for cereals like maize and millet (Tadesse, 2020). Mitigation Strategies are: Conservation Agriculture: Farmers have adopted techniques such as zai pits and mulching to enhance soil moisture retention, improving crop resilience to drought (Kebenei et al., 2023). Hermetic Storage Bags: The introduction of Purdue Improved Crop Storage (PICS) bags has significantly reduced moisture-related postharvest losses by preventing insect and mold infestation (Parmar et al., 2018). Solar Drying Technology: Low-cost solar dryers have been deployed to improve drying efficiency, reducing postharvest spoilage and mycotoxin contamination (Watson et al., 2024). Combining soil moisture conservation with improved postharvest storage techniques leads to higher food security. Community-level training programs enhance the adoption of best practices, ensuring long-term sustainability (Franco & Tracey, 2019). Investments in AI-driven drought forecasting tools help farmers make informed harvesting and storage decisions (Ashoka et al., 2024).

ii. Flood-Prone Regions: South Asia (Bangladesh)

Bangladesh is highly vulnerable to seasonal flooding, particularly during the monsoon season (Masum 2019). Excess moisture from floods leads to extensive postharvest losses, affecting staple crops such as rice. Challenges include: Floodwaters cause severe waterlogging, leading to delayed harvesting and increased spoilage, whereas contaminated water fosters the growth of molds and bacteria, reducing grain and vegetable quality (Ozcatalbas & Iyer-Raniga, 2024). Traditional open-air drying methods are ineffective due to high humidity, prolonging drying times and increasing the risk of fungal infections (Baidhe et al. 2024). Mitigation Strategies: Raised Storage Structures: Farmers have adopted elevated bamboo and concrete platforms to store grains, reducing flood-related damage (Sadeque, 2019). Improved Drainage Systems: Community-led initiatives have focused on constructing better drainage channels to prevent waterlogging in agricultural fields (Kaiser & Akter, 2025). Floating Agriculture: In low-lying flood-prone areas, floating gardens made from water hyacinths and bamboo have been used to sustain food production and reduce reliance on flood-affected land (Sarkar et al., 2025). Mechanical Drying and Moisture Monitoring: Rice processing mills have incorporated mechanical dryers and AI-based moisture sensors to improve postharvest grain quality (Patil & Chawla, 2024). Adaptation to local environmental conditions, such as raised storage and floating agriculture, is crucial in flood-prone areas. Investing in early warning systems and AI-powered flood prediction models helps farmers prepare for extreme weather events (Bhattacharjee et al., 2022). The combination of modern technology with traditional knowledge enhances the resilience of smallholder farmers (Sumane et al., 2018).

iii. Best Practices in Mitigating Postharvest Losses through Soil Moisture Management

Based on experiences from different tropical regions, several best practices have emerged as effective solutions for minimizing postharvest losses: Integrated Soil and Water Management: Combining conservation agriculture, improved drainage, and rainwater harvesting helps regulate soil moisture levels and prevent losses caused by droughts and floods (Sarvade et al., 2019). Postharvest Innovations: The use of hermetic storage, mechanical drying, and smart monitoring technologies significantly reduces spoilage and enhances food quality (Bradford et al., 2020). AI and Remote Sensing Applications: Data-driven decision-making, powered by AI-based predictive models and GIS mapping, improves resilience by providing timely information on soil moisture conditions (Obasi et al., 2024). Community-Based Approaches: Training programs and cooperative storage facilities improve knowledge-sharing and ensure broader adoption of best practices (Alhogail, 2021). Policy and Institutional Support: Governments and international organizations play a vital role in scaling up successful interventions and promoting access to modern postharvest technologies (Urugo et al., 2024).

POLICY AND INSTITUTIONAL INTERVENTIONS

Effective policy and institutional support are crucial for managing soil moisture extremes and reducing postharvest losses in tropical regions (Ssekyanzi & Park, 2023). Governments, international organizations, and research institutions play a vital role in developing and implementing strategies that enhance agricultural resilience (Urugo et al., 2024). This section explores key policy frameworks, investment priorities, and institutional interventions aimed at mitigating the effects of droughts and floods on soil moisture and postharvest management.

i. Role of Governments and International Organizations in Managing Soil Moisture and Postharvest Losses

Governments and international organizations are central to addressing soil moisture challenges and postharvest losses in tropical regions (Bradford et al., 2020). Their interventions focus on policy formulation, infrastructure development, funding, and capacity building (Kahwa et al., 2016). Government Initiatives. National Soil and Water Conservation Programs: Many tropical countries have implemented soil and water conservation initiatives, including rainwater harvesting, afforestation, and sustainable land management practices to mitigate soil moisture variability (Damtie et al., 2022). Postharvest Loss Reduction Strategies: Governments have introduced subsidies and grants for improved storage facilities, mechanized drying technologies, and hermetic storage bags to reduce losses (Baidhe et al., 2024). Disaster Preparedness and Early Warning Systems: National meteorological services provide climate forecasts and early warnings for droughts and floods, allowing farmers to take proactive measures (Van Ginkel & Biradar, 2021). International Organizations and Development Partners: Food and Agriculture Organization (FAO): FAO supports climate-smart agriculture, including soil moisture management and postharvest loss reduction through policy guidance and capacity-building programs (Matteoli et al., 2020). World Bank and African Development Bank (AfDB): These organizations fund infrastructure projects such as irrigation systems, storage facilities, and rural roads to enhance agricultural resilience (Ghosh et al., 2022). United Nations Development Programme (UNDP): UNDP assists in integrating climate adaptation strategies into national agricultural policies, focusing on sustainable water and soil management (Sanz et al., 2017). The Consultative Group on International Agricultural Research (CGIAR): CGIAR institutions, such as the International Institute of Tropical Agriculture (IITA) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), conduct research on drought-resistant crops and innovative postharvest technologies (Dinesh, 2016).

ii. Policy Frameworks for Climate Adaptation in Agriculture

Several policy frameworks guide climate adaptation efforts in agriculture, emphasizing soil moisture management and postharvest loss reduction (Stathers et al., 2020). National Climate Change Adaptation Plans (NAPs): Many tropical countries have developed NAPs to integrate climate resilience into agricultural policies, prioritizing soil and water conservation, irrigation infrastructure, and improved storage systems (Rackelmann et al., 2024). These plans promote the adoption of drought-resistant crops, agroforestry, and climate-smart irrigation techniques. Agricultural and Rural Development Policies. Governments have formulated policies encouraging sustainable land use, promoting conservation agriculture, and supporting smallholder farmers with climate adaptation strategies (Rodenburg et al., 2021). Extension services play a crucial role in disseminating information on soil moisture conservation and postharvest best practices. Trade and Market Policies for Reducing Postharvest Losses: Policies that improve market access, storage infrastructure, and transportation networks help reduce postharvest losses (Kaur & Watson, 2024). Regional trade agreements facilitate the movement of surplus produce from drought-affected areas to food-insecure regions (Awange, 2022). Water Resource Management Policies: Integrated Water Resource Management (IWRM) frameworks help regulate water use for irrigation, ensuring sustainable soil moisture levels in both drought- and flood-prone areas (Alamgir et al., 2024). Policies promoting rainwater harvesting and groundwater recharge enhance water availability for agriculture (Saha et al., 2024).

iii. Investment in Research, Technology, and Extension Services

Increased investment in research, technology, and agricultural extension services is essential for improving soil moisture management and reducing postharvest losses in tropical regions (Stathers et al., 2020). Research and Development (R&D) in Climate-Resilient Agriculture: Research institutions are developing drought-resistant crop varieties, improved irrigation technologies, and postharvest innovations tailored to tropical environments (Mkherjee et al., 2021). Investments in AI and remote sensing technologies enable real-time monitoring of soil moisture and climate risks (Gopal & Pitts, 2025). Adoption of Smart Agricultural Technologies: AI-Driven Soil Moisture Monitoring: Governments and private sector partners are promoting the use of AI-powered soil sensors and predictive analytics for better water management (Ashoka et al., 2024). Improved Postharvest Technologies: Investments in solar and mechanical drying, hermetic storage, and cold chain logistics help minimize losses (Bradford et al., 2020). GIS-Based Decision Support Systems: GIS applications aid policymakers and farmers in planning climate adaptation strategies. Strengthening Agricultural Extension Services: Extension agents play a key role in training farmers on soil moisture conservation, postharvest handling, and climate-resilient agricultural practices (Jegadeesan & Ramkumar, 2024). Digital extension platforms, including mobile apps and SMS-based advisory services, have expanded access to climate-smart agricultural knowledge (Haworth et al., 2018).

CONCLUSION AND RECOMMENDATIONS

Soil moisture dynamics play a critical role in agricultural productivity and postharvest loss reduction, especially in tropical regions prone to droughts and floods. This review highlights how extreme soil moisture conditions negatively impact crop quality, storage potential, and food security. Drought conditions lead to poor grain filling, increased pest infestations, and challenges in drying, while flooding results in waterlogging, delayed harvests, and contamination risks. Effective soil and water management strategies, combined with innovative postharvest technologies, are essential for mitigating these losses. Despite progress in soil moisture management, several knowledge gaps remain. More research is needed on AI-driven predictive models for soil moisture variability, localized soil moisture retention techniques, and cost-effective postharvest technologies suitable for smallholder farmers in the tropics.

There is a need for region-specific studies on the long-term effects of climate change on soil moisture and postharvest losses. To ensure sustainable agricultural resilience, governments and stakeholders should invest in adaptive policies, improved irrigation and drainage infrastructure, and farmer training programs. Integrating AI, remote sensing, and GIS technologies into soil moisture monitoring can enhance early warning systems and postharvest planning. Strengthening research collaboration between institutions and promoting knowledge transfer through extension services will further help farmers adopt best practices. Moving forward, a multi-disciplinary approach that combines policy support, technological innovation, and farmer-led solutions is necessary to enhance soil moisture management and reduce postharvest losses, ensuring food security and economic stability in tropical regions.

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