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Crop Residue Management Effects on Soil Temperature

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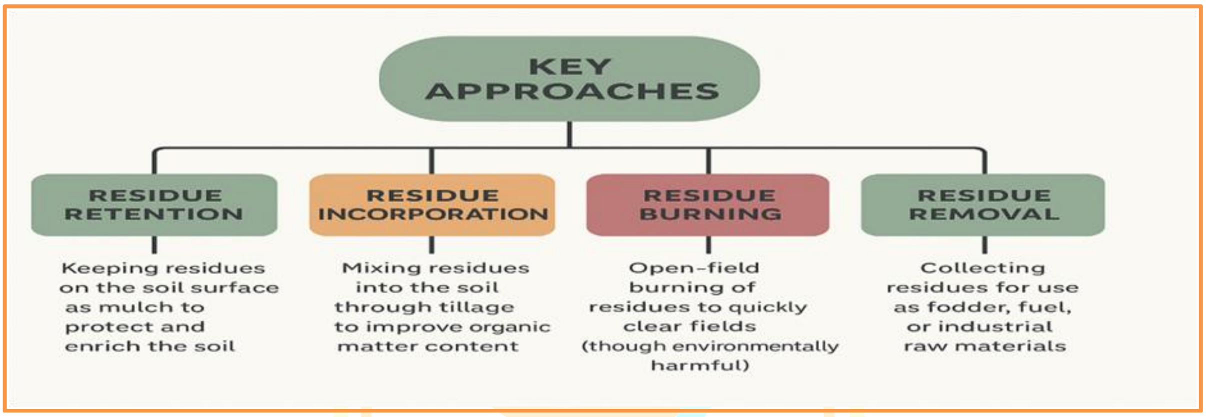
Residue management refers to the strategic handling, utilization, and disposal of crop residues that are the remaining plant materials such as stems, leaves, and roots left in the field after harvest, to maintain or enhance soil quality, crop productivity, and environmental sustainability.



Objectives of Residue Management

- Regulate soil temperature and moisture for optimal crop growth.
- Reduce erosion and surface runoff, protecting topsoil.
- Enhance soil organic carbon and promote nutrient cycling.
- Support conservation agriculture and mitigate greenhouse gas emissions.

Benefits of Crop Residue

- Acts as a soil amendment, improving fertility and structure.
- Provides erosion control and stabilizes soil aggregates.
- Moderates soil temperature and sustain microbial activity.
- Promotes nutrient recycling through residue decomposition.
- Reduces evaporation losses and enhances water-holding capacity.

Residue Retention Vs. Removal

Parameter	Retained Residues	Removed Residues
Soil Temperature	Lower and stable	Higher fluctuations
Soil Moisture	Increased	Decreased
Soil Erosion	Reduced	Higher risk
Microbial Activity	Enhanced	Reduced

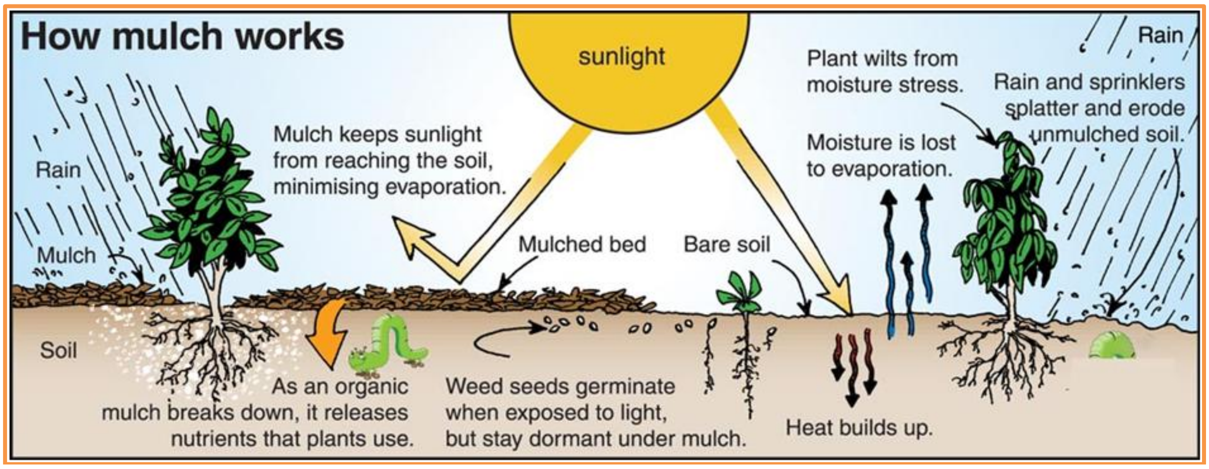


Figure: Mulched soil vs bare soil

Importance of Soil Temperature

Soil temperature refers to the degree of heat within the soil profile, which affects physical, chemical, and biological processes essential for plant growth and soil functioning.

a. **Role in Plant Growth:**

- ✓ Determines seed germination rate and uniformity.
- ✓ Influences root initiation, elongation, and nutrient absorption.
- ✓ Affects water uptake efficiency and transpiration.
- ✓ Optimum temperature for seed germination is 10°C to 35 °C and root growth is 20 °C to 25 °C

b. Impact on Microbial and Biological Activity:

- ✓ Soil microorganisms are highly sensitive to temperature fluctuations.
- ✓ Optimum temperatures enhance decomposition and nutrient mineralization.
- ✓ Optimum temperature for microbial activity is 25°C to 35 °C

c. Influence on Soil Physical and Chemical Processes:

- ✓ Regulates evaporation, soil aeration, and water viscosity.
- ✓ Affects chemical reaction rates, including nitrification and organic matter breakdown.
- ✓ Governs the exchange of gases (CO_2, O_2) between soil and atmosphere.

d. Implications for Crop Productivity:

- ✓ Stable soil temperature ensures uniform crop establishment.
- ✓ Extremes (too high or too low) lead to stress, poor root development, and yield reduction.

Factors Affecting Soil Temperature

a. Solar Radiation (Primary Source of Heat)

The intensity and duration of incoming solar radiation determine the daily and seasonal soil temperature patterns. Dark-colored soils absorb more heat, while lighter soils reflect radiation. Cloud cover, slope orientation, and shading alter radiation input.

b. Soil Moisture Content

Water has a high specific heat capacity, meaning wet soils warm up and cool down more slowly than dry soils. Moist soils maintain more stable temperature regimes, resulting in reduced daily fluctuations. Excess water, however, can lower soil temperature by limiting air movement and heat conduction.

c. Soil Texture and Structure

Sandy soils heat and cool rapidly due to low water-holding capacity. Clay soils retain moisture and have slower temperature changes. Well-structured soils enhance heat conduction and uniform temperature distribution.

d. Vegetative and Residue Cover

Crop residues, weeds, or plant canopies reduce solar radiation interception at the soil surface. Mulch acts as an insulating layer, maintaining moderate soil temperatures. Bare soil experiences greater diurnal fluctuations compared to covered soil.

e. Soil Colour and Organic Matter

Darker soils (rich in organic matter) absorb more radiation and tend to be warmer. Light-coloured soils reflect sunlight, resulting in cooler surface temperatures.

f. Tillage and Soil Management Practices

Tillage exposes moist subsoil to air, increasing heat exchange and drying. Conservation tillage and residue management stabilise soil temperature by minimising disturbance. Compacted soils restrict air and water movement, affecting heat transfer.

Mechanism of Soil Temperature Moderation by Residue Management

1. Reflection and Interception of Solar Radiation

The surface residue layer intercepts and reflects incoming short-wave radiation, reducing the direct heat flux into the soil. The albedo, or surface reflectivity, of a residue-covered soil is generally higher than that of bare moist soil, resulting in reduced absorption of solar radiation and consequently lower surface heating. In temperate climates, the presence of surface litter has been shown to reduce maximum soil temperatures by approximately 2–5 °C and increase minimum temperatures by about 1°C, effectively narrowing the diurnal temperature range and buffering soil thermal fluctuations (FAO, 2006).

Residue → ↑ reflection/ shading → ↓ daytime soil heating

2. Thermal Insulation and Heat Buffering

Beyond radiation, residue acts as a thermal insulator, slowing down heat exchange (both gain during the day and loss at night) between the soil surface and the atmosphere. Shen *et al.* (2018) conducted a field study in Northeast China to evaluate the thermal effects of maize stalk mulch on soil temperature. Their findings revealed that the weekly average soil temperature decreased by 0–1.9 °C under residue-covered plots compared to bare soil. The cooling effect was directly proportional to the amount of residue coverage, with higher mulch density resulting in greater temperature reduction. This thermal buffering was particularly beneficial during early crop growth stages, where stable soil temperatures support root development and microbial activity.

Residue → insulation barrier → ↑ thermal inertia / slower heat-loss at night → ↑ minimum soil temperatures, ↓ maximum soil temperatures.

3. Reduction of Daily Soil Temperature Amplitude (Day–Night Range)

Because residues both reduce daytime heating and slow nighttime cooling, the net result is a smaller difference between daily maximum and minimum soil temperature (i.e., reduced amplitude).In a study of tillage and straw mulching, the amplitude of the daily thermal wave at 2 cm depth under a straw mulch was about 79% of that at the surface, indicating damping of thermal fluctuations (Andrade *et al.*, 2009).Yin *et al.* (2020) noted that residue cover reduced diurnal temperature amplitude, stabilizing soil conditions in temperate zones.

Why this matters: Lower amplitude means more stable root zone conditions, less thermal stress for roots and microbes, and potentially better germination and early growth.

Residue Management Effect on Soil Temperature

The primary influence of crop residue left on the surface as a mulch is the moderation of soil temperature by:

Insulation and Reduced Heat Flux: Residue cover acts as a barrier, dampening the transfer of heat between the atmosphere and the soil. This effect is more pronounced at the soil surface (0-10 cm depth) and diminishes with depth.

Reduced Maximum Temperatures (Cooling Effect): During hot days or warm months, the residue layer shades the soil surface and has a higher albedo (reflects more solar radiation) than bare soil. This prevents the soil from absorbing as much solar energy, resulting in significantly lower daily maximum soil temperatures. Reductions can be substantial, sometimes lowering the temperature by several degrees Celsius compared to bare soil.

Increased Minimum Temperatures (Warming Effect, Less Pronounced): In some cases, particularly in cold farming areas or during the early spring, the insulating property of the residue can help trap heat at night, resulting in slightly higher minimum soil temperatures compared to bare soil. This can be beneficial for earlier crop growth in colder climates. However, in cold conditions, a heavy residue layer can also lead to lower average temperatures, delaying soil warming for spring planting.

Reduced Diurnal Fluctuation: The overall effect is a stabilization of soil temperature, significantly reducing the difference between the day's maximum and minimum temperatures (diurnal range).

Effect of Tillage and Residue Management

The combination of tillage and residue management defines the overall impact:

No-Tillage (No-Till) with Residue Retention: This is the most effective method for moderating and lowering soil temperature during warm periods due to the uninterrupted surface mulch. This is beneficial in warmer climates or during dry, hot seasons for reducing moisture evaporation and heat stress on roots.

Conventional Tillage (CT) or Residue Incorporation: When residues are incorporated into the soil by ploughing or other intensive tillage, the temperature-moderating benefits of the surface mulch are largely cancelled out. The dark, bare soil surface under CT absorbs more solar radiation, leading to higher maximum soil temperatures during the day and a wider diurnal range.

Residue Amount: The amount of residue coverage matters. Generally, higher percentages of surface cover lead to greater temperature moderation (more cooling during the day). However, an excessive amount of residue in cold regions can delay spring warming, potentially hindering early-season seed germination and root development.

Importance for Plant Growth

Soil temperature regulation is crucial because it influences several biological and physical processes:

Seed Germination: Optimal soil temperature is essential for successful germination. Too-high temperatures (typical in bare, tilled soil during summer) can inhibit germination and hinder initial root development.

Nutrient and Water Uptake: High soil temperatures can stress the plant and inhibit root growth, reducing the plant's ability to take up water and nutrients.

Microbial Activity: Soil temperature and moisture greatly influence the activity of soil microbes, which are responsible for the decomposition of organic matter and the cycling of nutrients.

Challenges in Residue Management

Managing crop residue to optimize soil temperature presents several key challenges, especially when balancing the benefits of residue (like moisture retention) with the need for optimal conditions for seed germination and early crop growth. The primary conflict arises between the cooling and insulating effects of the residue and the need for early spring warming in temperate or cold climates.

1. **Delayed Spring Warming in Cold/Temperate Climates**

The most significant challenge is the delay of soil warming in the spring under heavy residue cover (e.g., in No-Till systems).

Insulation Effect: The thick layer of mulch acts as an insulator, preventing solar radiation from directly heating the soil surface. This is particularly problematic during the planting season when ambient temperatures are low.

Albedo Effect: Residues, which are typically lighter in color than dark, moist soil, have a higher albedo (reflect more sunlight). This reduces the net energy absorbed by the soil.

Impact on Germination: Delayed warming can push the soil temperature below the minimum threshold required for the rapid germination of major crops like corn, cotton, or sunflower. This leads to delayed planting, slowed emergence, and potentially reduced final yields.

Solution Trade-off: Strategies to mitigate this, such as removing residue from the seed row (*strip-tillage* or *residue movers*), compromise the full benefits of continuous residue cover (e.g., erosion control).

2. High Temperatures and Seedling Heat Stress in Arid/Tropical Climates

While residue generally cools the soil, managing it in hot, arid, or tropical environments presents a different set of challenges related to the intensity of heat.

Residual Heat in Residue: While surface temperatures are lower, if the residue is very dry, it can trap heat, and while it insulates against the peak solar load, the total amount of energy absorbed by the system can still lead to high soil temperatures.

Heat Stress Paradox: In very hot periods, even the cooler soil under mulch might still be above the optimum temperature for certain crop roots, especially if soil moisture is limited.

3. Managing Variable Residue Amounts

The amount, type, and distribution of residue significantly influence its temperature-regulating effect, making consistent management difficult.

Crop-Specific Differences: Different crops produce different residue amounts (e.g., corn vs. soybeans) and have varying chemical compositions (C:N ratio), which affects their decomposition rate and persistence.

Non-Uniform Coverage: Residue is rarely spread perfectly uniformly across the field. Heavy clumps can create excessively cool and wet spots, leading to poor seed performance, while bare patches can overheat.

Need for Precision: Effective residue management requires adjusting practices (e.g., vertical tillage, chopping, or moving) based on the specific residue load, which adds complexity and cost to farm operations.

4. Soil-Residue-Moisture Interaction

Soil moisture content and residue management are intrinsically linked, and their interaction complicates temperature control.

Higher Soil Moisture: Residue-covered soil tends to retain more moisture. While this is crucial for drought resistance, wet soil takes longer to warm up than dry soil because water has a high specific heat capacity. This exacerbates the delayed spring warming challenge.

Evaporative Cooling: The residue prevents surface evaporation, which is a natural cooling process. When residue is removed, increased evaporation can sometimes offer a short-term cooling effect, though the long-term benefit of retaining moisture under the mulch usually outweighs this.

5. Equipment and Operational Challenges

Implementing temperature-optimizing residue management often requires specialized equipment and careful timing.

Specialized Machinery: Equipment like row cleaners or strip-tillage units is needed to move residue away from the seed row to promote localized warming, increasing equipment investment.

Field Operations Timing: The effectiveness of temperature management depends on the timing of planting relative to soil conditions. If spring is cool and wet, even light residue can significantly delay planting until the soil reaches the critical temperature for germination.

Climate Change Relevance of Residue Management

Mitigating Climate Impacts

1. Temperature Buffering: Residue cover moderates soil temperature extremes, reducing heat stress in warming climates and preserving warmth in cooler seasons.
2. Carbon Sequestration: Decomposing residues contribute to soil organic carbon pools, enhancing long-term carbon storage and reducing atmospheric CO_2.

Enhancing Climate Resilience

1. **Moisture Conservation**: Residue reduces evaporation, improving water-use efficiency under erratic rainfall and prolonged dry spells.
2. **Microbial Stability:** Stable soil temperatures support microbial diversity and function, crucial for nutrient cycling under climate stress.

Supporting Sustainable Agriculture

1. **Extended Growing Seasons:** Thermal moderation enables earlier planting and longer cropping windows in variable climates.

2. **Reduced Emissions**: Minimizing residue burning lowers greenhouse gas emissions (GHGs), especially methane (CH_4) and nitrous oxide (N_2O).

Practical Recommendations for Residue Management

Agronomic Best Practices:

Select Appropriate Residue Type: Use non-allelopathic residues (e.g., wheat, maize) for sensitive crops.

Optimize Residue Quantity: Maintain 30–50% surface coverage to balance insulation and sowing ease.

Uniform Distribution: Ensure even spreading to avoid patchy soil temperature and moisture zones.

Field-Level Implementation

Use Conservation Tillage Tools: Adopt Happy Seeder, Turbo Seeder, or Strip Till drills for residue-retained sowing.

Shred and Incorporate Strategically: Shredding improves decomposition and minimizes sowing interference.

Monitor Soil Temperature: Use sensors or thermal probes to guide sowing timing and residue adjustments.

Site-Specific Adaptation

Tailor to Climate Zone: In hot climates, retain residues for cooling; in cold zones, use thinner layers to avoid delayed warming.

Integrate with Crop Rotation: Match residue type and quantity to seasonal crop needs and decomposition rates.

Summary

Residue management plays a critical role in regulating soil temperature, offering both cooling effects in hot climates and warming benefits in cold regions. By moderating diurnal temperature fluctuations, residue cover enhances seed germination, root development, and microbial activity, while also conserving moisture and contributing to soil organic carbon buildup. These thermal and biological benefits support climate-resilient agriculture, though challenges such as equipment limitations, pest risks, and regional variability persist. Practical solutions—including conservation tillage tools, uniform residue distribution, and policy support—can help optimize residue use for sustainable soil health and crop productivity.

References

1. Andrade, J., Alexandre, C., & Basch, G. (2009). Mulching and soil tillage influence on the thermal behaviour of a Luvisol surfacel layer. *Sustainable development*.
2. FAO (2006). Plant nutrition for food security: A guide for integrated nutrient management. Food and Agriculture Organization of the United Nations, Rome.
3. Shen, Y., McLaughlin, N., Zhang, X., Xu, M., & Liang, A. (2018). Effect of tillage and crop residue on soil temperature following planting for a Black soil in Northeast China. *Scientific reports*, **8**(1), 4500. https://doi.org/10.1038/s41598-018-22822-8
4. Yin, T., Yan, C., Liu, Q., & He, W. (2020). No-tillage combined with residue retention and plastic mulching improves maize yields in a cold semiarid region of northern China. *European Journal of Soil Science*, **71**(6), 1144-1156.