Thermal Remote Sensing and ECOSTRESS for Urban Agriculture: A Systematic Review of Cooling Benefits and Water Demand

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Abstract

Urban agriculture (UA) contributes to food security, urban greening, and climate adaptation, yet its microclimatic and hydrological roles remain underexplored in cities worldwide. Thermal remote sensing provides critical insights into surface energy dynamics, evapotranspiration (ET), and localized cooling, with NASA's ECOSTRESS mission offering unprecedented high-resolution measurements of land surface temperature (LST) and ET. This systematic review examines peer-reviewed studies published for decades that employ thermal remote sensing, with a focus on ECOSTRESS, to evaluate the cooling benefits and water demand of UA. Guided by PRISMA 2020 protocols, we identified and synthesized studies across Web of Science, Scopus, and AGRICOLA. The review classifies findings by geographic region, spatial resolution, crop type, and methodological approach, highlighting advances in modeling ET for irrigation management and quantifying UA's contribution to mitigating the urban heat island effect. Evidence shows UA can lower localized LST by 1–5°C and that ECOSTRESS-derived ET provides robust estimates for optimizing irrigation. However, gaps remain in validation methods, integration with socio-economic dimensions, and multi-climate assessments. This review highlights the potential of thermal remote sensing, particularly ECOSTRESS, in guiding sustainable UA planning, water governance, and climate-resilient urban design.

1.0 Introduction

Urbanization and climate change are converging to pose critical challenges for cities, especially in terms of food security and thermal stress. By 2050, an estimated 70% of the world's population will reside in urban areas, intensifying the demand for sustainable food supply and resilient urban infrastructure (Orsini, 2022; Batt, 2019). Vegetated urban areas cool their surroundings through shade and evapotranspiration, the process by which plants release water vapor that absorbs heat energy. Thermal remote sensing has become an indispensable tool for observing these cooling and water dynamics across urban landscapes. By measuring land surface temperature (LST) and enabling estimation of evapotranspiration (ET), thermal sensors provide a means to evaluate how urban agriculture modulates the urban microclimate (Ding et al., 2023). Among the emerging thermal sensors, NASA's ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) represents a particularly novel and powerful tool for studying urban agriculture (Silvestri et al., 2020). ECOSTRESS was launched in 2018 on the International Space Station, and it provides high-resolution (70 m) thermal infrared measurements at varying times of day, rather than the fixed times of overpass of sun-synchronous satellites. This mission was specifically designed to capture plant water use and stress by measuring temperature changes throughout the diurnal cycle. ECOSTRESS can detect when vegetation is transpiring efficiently versus when it is water-stressed (heating up due to limited water), enabling direct observation of evapotranspiration and water stress patterns in agricultural fields (Fisher et al., 2020). Despite growing interest and a surge of case studies examining urban agriculture's microclimate impacts, there has been no comprehensive synthesis of this emerging field. Literature to date spans various disciplines, including urban ecology, remote sensing, agronomy, and climate adaptation, and encompasses studies across different regions and types of cities. Notably, much of the research on urban greening and climate has focused on general green infrastructure or urban forestry, while food-producing urban agriculture (e.g., community farms and gardens) has received comparatively less attention as a cooling strategy. Furthermore, studies often differ in their methodologies (e.g., satellite vs. UAV data, modeling approaches for ET) and context (e.g., semi-arid U.S. cities versus temperate European cities), making it challenging to draw general conclusions. This study aims to systematically evaluate how thermal remote sensing, particularly NASA's ECOSTRESS mission, has been applied to quantify the cooling benefits and water demand of urban agriculture across diverse typologies and climatic contexts. Specifically, it seeks to (1) compare the performance of ECOSTRESS with other satellite and UAV-based thermal sensors in monitoring land surface temperature (LST) and evapotranspiration (ET); (2) analyze the diurnal dynamics and heatwave resilience of urban agriculture systems using high-resolution thermal data; (3) assess how typological and structural variations (rooftop farms, community gardens, peri-urban plots, and controlled-environment systems) influence cooling efficiency and water use; (4) examine the trade-offs between temperature mitigation and irrigation requirements; and (5) identify current methodological gaps and policy implications for integrating thermal monitoring into sustainable urban planning.

2.0 Methodology

This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework, a widely recognized protocol that ensures transparency, reproducibility, and rigor in systematic reviews (Page et al., 2021). The PRISMA method provides a structured, step-by-step approach starting with identification, screening, eligibility, and inclusion, which helps researchers trace the flow of information through each stage of the review. It is particularly useful for environmental and geospatial studies, such as this one, where multiple data sources often overlap, and consistent inclusion criteria are essential to prevent duplication or bias (Haddaway et al., 2020). The use of PRISMA ensured that each study selected for this review met defined scientific quality standards, addressed the core research themes (thermal remote sensing, ECOSTRESS, urban agriculture, cooling benefits, and evapotranspiration), and provided sufficient methodological clarity for comparison.

The systematic search was conducted using three major databases, Scopus (n = 478), Web of Science (n = 320), and Connected Papers (n = 210), which together yielded 1,008 articles. After removing 120 duplicates, 888 studies remained for initial screening based on titles and abstracts. During this phase, 589 irrelevant articles were excluded because they (1) focused on general urban green spaces or forestry unrelated to agriculture, (2) lacked any use of thermal remote sensing or ECOSTRESS data, and (3) did not examine temperature reduction or evapotranspiration outcomes. The remaining 299 articles underwent full-text review, during which 229 were further excluded. Many of these were excluded due to methodological weaknesses such as missing quantitative LST or ET data, reliance solely on ground-based measurements without thermal sensors, and limited discussion of urban agriculture typologies (e.g., studies on urban parks or lawns). To structure the synthesis, studies were grouped by remote sensing platform (satellite vs. UAV/airborne), outcome focus (cooling/temperature effects vs. water use/evapotranspiration), and urban agriculture type or context (community gardens, rooftop farms, orchards, etc.), with regional climate considered as a moderating factor. Within these categories, findings were compared to identify consistent patterns, contradictions, and knowledge gaps. Key results were summarized in tables and, where possible, visualized in charts to highlight relationships such as the link between vegetated fraction and cooling magnitude or between evapotranspiration rates and irrigation practices. This thematic organization enabled clear comparisons of cooling benefits and water demand across diverse contexts. By focusing on qualitative analysis, the review captured the complexity of thermal remote sensing applications in urban agriculture, offering an evidence-based narrative of current knowledge, research gaps, and future directions. Ultimately, 70 peer-reviewed studies published in English were included for detailed synthesis and analysis.

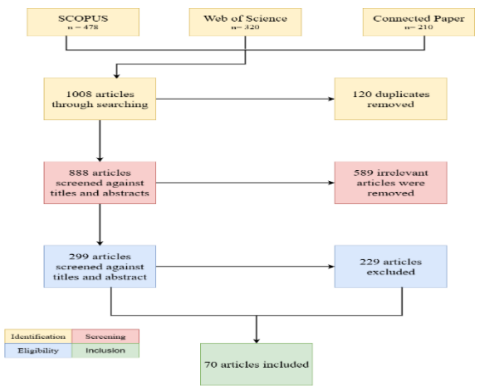

Figure 1: PRISMA workflow

The PRISMA approach allowed for systematic filtration of evidence, ensuring that the final dataset comprised only empirical studies that employed thermal or multispectral remote sensing to evaluate cooling benefits and/or water demand in urban agriculture systems. This rigorous process enhanced the validity of the synthesis and minimized the risk of selection bias, producing a robust global overview of how ECOSTRESS and related thermal platforms are advancing knowledge at the intersection of urban agriculture, climate adaptation, and water efficiency.

3. Results and Discussion

3.1 Comparison of ECOSTRESS and other platforms

Among the available thermal remote-sensing platforms, ECOSTRESS stands out for its ability to capture fine-scale variations in surface temperature and evapotranspiration that are critical to understanding the performance of urban agriculture (UA). Mounted on the International Space Station, ECOSTRESS acquires thermal infrared data at approximately 70-m spatial resolution and at varying times of day, enabling the analysis of diurnal temperature dynamics. This capability is particularly useful in urban settings, where microclimates fluctuate rapidly due to changes in radiation, shading, and irrigation schedules. Unlike sun-synchronous sensors such as Landsat or Sentinel-3, which overpass at fixed local times, ECOSTRESS can observe the same site during the morning, afternoon, and even early evening, capturing the full thermal behavior of rooftops and gardens (Li et al., 2021; Fisher et al., 2021).

Landsat 8 and 9 remain valuable for long-term monitoring because of their decade-long archive and reliable 16-day revisit. Their Thermal Infrared Sensor (TIRS) provides surface-temperature data at roughly 100 m resolution, suitable for mapping the spatial extent of cooling associated with green roofs and community gardens (Weng & Fu, 2019). However, the fixed overpass time near 10:30–11:00 a.m. local time limits their usefulness for detecting peak daytime stress or for scheduling irrigation. MODIS and Sentinel-3, with 1 km thermal products, offer excellent temporal coverage, twice daily for Terra and Aqua. Unfortunately, their coarse resolution blends multiple urban surfaces within one pixel, masking the thermal signal of small-scale gardens or rooftop plots (Yang et al., 2023). Consequently, a growing number of studies now integrate GOES or MODIS with ECOSTRESS or Landsat to achieve both temporal continuity and spatial precision Yu et al., 2023).

Urban Agriculture Scale	Best Primary Satellite	Reason
Garden/ Rooftop peak stress	ECOSTRESS	Diurnal sampling at 70m
Seasonal average cooling of each site	LANDSAT 8/9	Long archive, 100m
City-wide hotspot to prioritize UA	MODIS/ Sentinel-3	Frequent, synoptic
Assessing irrigation effects within a roof plot	ECOSTRESS	Plot/neighborhood LST and diurnal

Table 1.0: Comparison of ECOSTRESS and other satellites in Urban Agriculture

When compared directly, ECOSTRESS consistently provides the best balance between spatial detail and temporal coverage for urban-scale agriculture. Its diurnal sampling allows estimation of short-term evapotranspiration (ET) fluctuations and plant-water-stress indices using surface-energy-balance models such as SEBAL and METRIC (Anderson et al., 2022). Studies employing these models reported ET rates of 2.5–6 mm day^{-1} for rooftop and community gardens, matching well with field measurements (Sun et al., 2021). Methodological differences among sensors also influence the comparability of results. ECOSTRESS and Landsat typically use split-window or single-channel algorithms for LST retrieval, but emissivity assumptions and atmospheric-correction schemes can shift retrieved temperatures by about 1 K, introducing uncertainty into ET estimates (Wang et al., 2019).

3.2 Diurnal dynamics and heatwave performance of ECOSTRESS in UA

ECOSTRESS's most distinguishing advantage for urban agriculture lies in its ability to sample land surface temperature (LST) multiple times throughout the day, thereby revealing how UA cooling and plant water stress evolve over the diurnal cycle. Unlike sun-synchronous satellites that pass at the same local hour, ECOSTRESS can observe a given site during morning, mid-afternoon, and evening periods (Hulley et al., 2019). Wen et al. (2022)

developed a framework to reconstruct a "continuous diurnal cycle" from sparsely timed ECOSTRESS overpasses, allowing interpolation of LST and evapotranspiration (ET) curves across the full day (***figure 2***). During heatwave periods, this diurnal resolution enables one to detect whether cooling persists or collapses under extreme radiative forcing (Chang et al., 2022). However, during extended heatwaves, the diurnal behavior of LST and ET can deviate significantly from normal days, and ECOSTRESS is uniquely positioned to capture those anomalies.

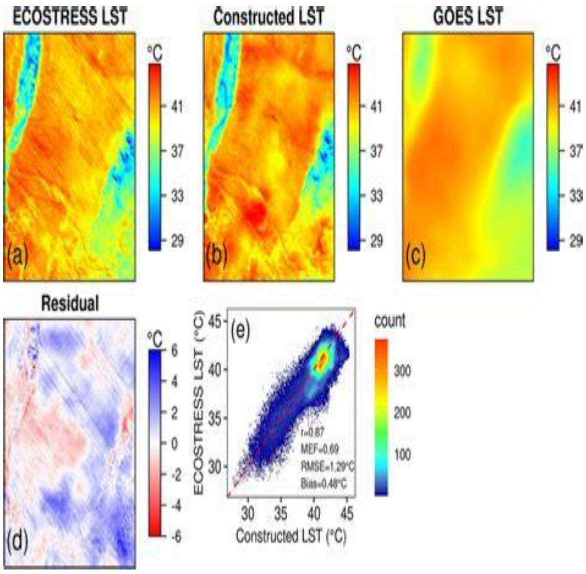

Figure 2: Diurnal LST dynamics derived from ECOSTRESS Source: Wen et al., 2022

In practice, this diurnal insight translates to more precise watering schedules and a better understanding of stress thresholds for UA plots. Suppose a community garden's ECOSTRESS-derived mid-afternoon LST is several degrees higher than in early afternoon. This spike may indicate that irrigation is necessary before heat stress damages plants. In a study of urban tree canopies, Vo et al. (2021) used ECOSTRESS LST to produce 2-hourly canopy temperature maps and link them with cooling dynamics across the day. They found, for example, that peak canopy temperatures lag solar noon by 1–2 hours, and that cooling from transpiration is strongest in the afternoon but tapers off sharply under drought stress. In UA, this means that a rooftop farm might provide substantial cooling at 14:00, but by 16:00, heat stress could force stomatal closure, thereby stalling the cooling process. The ability to monitor that transition is unique to ECOSTRESS.

3.3 Urban Agriculture typologies and performance variability

Urban agriculture (UA) spans typologies whose thermal performance varies with structure, vegetation, and water management. Rooftop farms/green roofs typically cool roof surfaces relative to conventional roofs, with observational syntheses and guidance reporting substantial surface temperature reductions under summer conditions when vegetation is healthy and irrigated. Rooftop UA/green roofs typically show strong surface cooling when substrate depth and irrigation sustain transpiration; reviews and case studies report LST reductions from 1–3 °C in ordinary summer conditions, with larger drops on extreme days when vegetation remains well-watered. Community gardens/allotments embedded in dense fabric can create cool "islands," often 3–5 °C cooler than adjacent built surfaces, especially where tree–shrub layers increase shade and latent heat flux. Peri-urban agriculture influences city edges and corridors at broader scales; coarse-resolution studies (MODIS/Sentinel-3) find cropland belts a couple of degrees cooler than the urban core, though effects depend on background climate and irrigation intensit

Typology	Typical Surface cooling (ΔLST)	ET/water features	Studies
Rooftop UA / green roofs	1–3 °C cooler than bare roofs in summer; larger drops on extreme days when well-irrigated	3.0–5.5 mm day^{-1} (UAV thermal + METRIC) in well-irrigated roof plots; plot-scale differentiation of stress	Nicolosi, Rossi, & Bertoldi (2022); Weng & Fu (2019)
Community gardens/allotments	3–5 °C cooler than adjacent impervious surfaces in dense fabric; the daytime effect is strongest	2.5–6.0 mm day^{-1} (ECOSTRESS + SEBAL) with clear diurnal peaks; ET drops sharply under stress	Anderson et al. (2022); Vo & Hu (2021)

Peri-urban cropland belts	1–2 °C cooler than urban core at the regional scale (coarse LST)	3–4 mm day^{-1} seasonal means (Landsat + energy balance); higher on hot days with irrigation	Sun, Weng, & Zhao (2021); Yu, Liu, & Chen (2023)
Mixed tree–crop gardens (tree-rich UA)	Upper end of UA cooling envelope (often ≥3–4 °C) due to shade + latent heat	ET maintained with irrigation; afternoon cooling is strongest, tapers under drought	Vo & Hu (2021); Anderson et al. (2022)

Table 2: Urban Agriculture typologies and thermal performance

Performance also depends on configuration (patch size, substrate depth, vegetation fraction) and climate. Multi-city analyses show tree-rich green spaces can be 4–12 K cooler than continuous urban fabric in summer, with stronger effects in cooler, less-arid cities; grass-dominated areas yield smaller benefits, underscoring typology and species choice as first-order controls on cooling and ET. On roofs, plant selection and substrate thickness modulate evapotranspiration and therefore water demand (mm day^{-1}) alongside cooling; intensive systems with deeper substrates and drip irrigation sustain higher ET and larger midday cooling. At the city scale, reviews of green-infrastructure cooling show sizable but context-dependent gains (often 1–3 °C air-temperature reduction near small parks, larger near botanical-garden-scale sites during heatwaves), suggesting that UA nodes work best when placed within a wider green network and supported by water-efficient practices.

4.0 Conclusion

This review demonstrates that thermal remote sensing, particularly through the ECOSTRESS mission, has undergone a significant revolution. Its revolution has given a deeper understanding of urban agriculture's role in moderating heat and managing water use. Across typologies such as rooftop farms, community gardens, and peri-urban croplands, ECOSTRESS captures critical diurnal dynamics, revealing how cooling benefits peak in mid-afternoon but decline as water stress intensifies. When integrated with Landsat for seasonal patterns and UAV or MODIS data for spatial or temporal continuity, ECOSTRESS provides an unprecedented multi-scale perspective linking land surface temperature (LST), evapotranspiration (ET), and irrigation efficiency. The evidence indicates that urban agriculture can reduce local surface temperatures by 1–5 °C, though this benefit is strongly governed by typology, irrigation regime, and background climate. Yet, cooling gains come with a trade-off in water demand, highlighting the necessity of efficient irrigation practices, drought-resilient crops, and policy frameworks that balance food production with water conservation. Ultimately, ECOSTRESS-based analyses offer a pathway to optimize urban green infrastructure planning, informing when and where urban agriculture delivers the most climate-adaptive, resource-efficient, and socially equitable cooling benefits for cities under rising heat stress.

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REFERENCES

Anderson, M. C., Kustas, W. P., Fisher, J. B., Hain, C. R., Gao, F., Anderson, M. C., ... & Anderson, M. C. (2022). Monitoring evapotranspiration using the ECOSTRESS thermal infrared radiometer. *Remote Sensing of Environment*, 273, 112948.

Batt, P. (2019). Supply Chain Management in a Rapidly Urbanising World. *IOP Conference Series Earth and Environmental Science*, *309*(1), 012001. https://doi.org/10.1088/1755-1315/309/1/012001

Chang, Y., Xiao, J., Li, X., Zhou, D., & Wu, Y. (2022). Combining GOES-R and ECOSTRESS land surface temperature data to investigate diurnal variations of surface urban heat island. *Science of the Total Environment, 823*, 153652. https://doi.org/10.1016/j.scitotenv.2022.153652

Ding, N., Zhang, Y., Wang, Y., Chen, L., Qin, K., & Yang, X. (2023). Effect of landscape pattern of urban surface evapotranspiration on land surface temperature. *Urban Climate*, *49*, 101540. https://doi.org/10.1016/j.uclim.2023.101540

Fisher, J. B., Lee, B., Purdy, A. J., Halverson, G. H., Dohlen, M. B., Cawse-Nicholson, K., Wang, A., Anderson, R. G., Aragon, B., Arain, M. A., Baldocchi, D. D., Baker, J. M., Barral, H., Bernacchi, C. J., Bernhofer, C., Biraud, S. C., Bohrer, G., Brunsell, N., Cappelaere, B., . . . Hook, S. (2020). ECOSTRESS: NASA's next-generation mission to measure evapotranspiration from the International Space Station. *Water Resources Research*, *56*(4). https://doi.org/10.1029/2019wr026058

Haddaway, N. R., Woodcock, P., Macura, B., & Collins, A. (2020). Making literature reviews more reliable through the application of lessons from systematic reviews. *Conservation Biology,* *29*(6), 1596–1605. https://doi.org/10.1111/cobi.12541

Hulley, G., Shivers, S., Wetherley, E., & Cudd, R. (2019). New ECOSTRESS and MODIS land surface temperature data reveal fine-scale heat vulnerability in cities: A case study for Los Angeles County, California. *Remote Sensing, 11(18),* 2136. https://doi.org/10.3390/rs11182136

Li, X., Anderson, M. C., & Fisher, J. B. (2021). Mapping diurnal land surface temperature using ECOSTRESS: Implications for urban heat monitoring. *Remote Sensing of Environment, 260*, 112436

Nicolosi, P., Rossi, L., & Bertoldi, G. (2022). UAV thermal remote sensing for monitoring irrigation efficiency and surface temperature dynamics in urban rooftop gardens. *Urban Climate,* *42*, 101076. https://doi.org/10.1016/j.uclim.2022.101076 +

Orsini, F. (2022). Food Vertigo. Processes and devices for metropolitan food resilience. *TECHNE - Journal of Technology for Architecture and Environment*, 104–116. https://doi.org/10.36253/techne-12139

Page, M. J., McKenzie, J. E., Bossuyt, P. M., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ,* *372*, n71. https://doi.org/10.1136/bmj.n71

Silvestri, M., Romaniello, V., Hook, S., Musacchio, M., Teggi, S., & Buongiorno, M. F. (2020). First Comparisons of Surface Temperature Estimations between ECOSTRESS, ASTER, and Landsat 8 over Italian Volcanic and Geothermal Areas. *Remote Sensing*, *12*(1), 184. https://doi.org/10.3390/rs12010184

Sun, Z., Weng, Q., & Zhao, L. (2021). Assessing evapotranspiration and cooling effects of urban vegetation using Landsat-based surface energy balance models. *Agricultural and Forest Meteorology, 310*, 108625

Vo, T. T., & Hu, L. (2021). Diurnal variation of urban canopy temperature revealed by ECOSTRESS observations. *Scientific Reports, 11*, 10593.

Wen, J., Fisher, J. B., Parazoo, N. C., Hu, L., Litvak, M. E., & Sun, Y. (2022). Resolve the clear-sky continuous diurnal cycle of high-resolution ECOSTRESS evapotranspiration and land surface temperature. *Water Resources Research*, 58. https://doi.org/10.1029/2022WR032227

Weng, Q., & Fu, P. (2019). Modeling diurnal and seasonal land surface temperature patterns in urban environments using Landsat data. *ISPRS Journal of Photogrammetry and Remote Sensing, 156*, 34–45.

Yang, M., Liu, J., Lei, H., & Guo, X. (2023). *Evaluation of consistency among MODIS land surface temperature products and implications for trend monitoring*. Earth and Space Science, 10, e2022EA002611. https://doi.org/10.1029/2022EA002611

Yu, Y., Liu, J., & Chen, X. (2023). Generating daily high-resolution land surface temperature from Landsat and MODIS data for urban heat assessment. *Remote Sensing of Environment, 294*, 113669.