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The Use of Unmanned Aerial Vehicles (UAVs) in Landscape Planning: The case of Smart Farming in an Agricultural Landscape

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Abstract

Unmanned Aerial Vehicles (UAVs) are transforming both landscape planning and smart farming by delivering high-resolution, flexible, and cost-effective spatial data. This paper synthesizes current applications of UAVs in ecological monitoring, land-use planning, and precision agriculture, emphasizing their role in bridging farm-level management with regional planning goals. Drawing from recent advances in sensors, machine learning, and participatory approaches, the paper integrates a field-based case study from Adana, Türkiye, where UAV multispectral and thermal imagery were employed in wheat fields under controlled irrigation and nitrogen regimes. This Mediterranean example demonstrates how UAV-based monitoring can provide empirical evidence for linking farm-level diagnostics to landscape-scale resilience planning. The study concludes with methodological and governance insights for embedding UAV workflows into climate-resilient land-use systems.

Keywords: *Unmanned Aerial Vehicles (UAVs), Landscape Planning, Climate Resilience, Land Use, Smart Farming*

1. Introduction

Unmanned Aerial Vehicles (UAVs, "drones") have moved from niche ecological tools to mainstream instruments in spatial planning and agricultural management, largely because they deliver on-demand, centimeter-scale observations that bridge the scale gap between plot measurements and satellite remote sensing. This "meso-scale" capability is particularly valuable for landscape planners who deal with fine-grain ecological patterns while maintaining regional context (Sun et al., 2021; Anderson & Gaston, 2025). Across the last decade, UAVs have diversified from RGB photography to multispectral, thermal, and LiDAR payloads, producing orthomosaics, digital surface/elevation models (DSM/DEM), canopy models, and condition indices (e.g., NDVI, NDRE). These products support habitat mapping, fragmentation metrics, and change detection at planning-relevant resolutions (Robinson et al., 2022; Kamarulzaman et al., 2023). Some of the sensor types carried by UAVs, examples, application domains and key metrics are given in Table 1.

Table 1. Summary Table of UAV Sensors, Indices, and Applications

Sensor Type	Example Indices / Data	Application Domain	Key Metrics	References
RGB	VARI, ExG, canopy cover, stand counts	Crop emergence, canopy closure, urban vegetation mapping	Plant density, canopy % cover	Alves et al., 2024; Kamarulzaman et al., 2023
Multispectral (Red-Edge, NIR)	NDVI, NDRE, SAVI	Nutrient status, vigor mapping, habitat classification	Chlorophyll content, biomass proxy	Tanaka et al., 2024; Zhang et al., 2025; Villarreal et al., 2025
Thermal	CWSI, canopy temperature	Irrigation scheduling, drought stress, urban heat mapping	Leaf water potential, evapotranspiration	Dong et al., 2024; Araújo-Paredes et al., 2022; Yadav et al., 2024
LiDAR / Photogrammetry	DEM, DSM, canopy height models	Geomorphic change, tree structure, restoration monitoring	Elevation, slope, canopy height	Sestraș et al., 2025; Hu & Minner, 2023
Data Fusion (UAV + Satellite + Ground)	Pixel- and feature-level fusion, multimodal ML	Scaling diagnostics, regional planning, compliance monitoring	Yield prediction accuracy, upscaling robustness	Bazrafkan et al., 2025; Bongomin et al., 2024; Fathololoumi et al., 2025

In urban and peri-urban contexts, UAVs augment city-scale base maps with ultra-high-resolution layers for tree canopy condition, micro-green spaces, and roofscapes, and are integrated into digital twin workflows for planning scenarios (Shao et al., 2021; Hu & Minner, 2023). Beyond mapping, UAV imagery acts as a boundary object that enhances stakeholder engagement in participatory planning (Kleinschroth et al., 2022).

Methodologically, UAVs catalyze a shift from static inventories to operational monitoring, enabling time-series analyses of vegetation, geomorphic change, and restoration progress (Sestraș et al., 2025). However, standardization still remains a critical gap in this process (Sun et al., 2021; Anderson et al., 2025).

Meanwhile, in agriculture, UAV sensing coupled with AI/ML supports early disease detection, irrigation optimization, and precision spraying, reducing inputs while sustaining yields (Agrawal & Arafat, 2024; Guebsi et al., 2024; Narzari et al., 2025). Challenges include scale mismatch, regulatory diversity, computational burdens, and barriers to uptake among smallholders (Kamarulzaman et al., 2023; Aliloo et al., 2024; Dobrinić et al., 2025). Future opportunities include multi-sensor fusion, standardized protocols, and participatory visualization, positioning UAVs as decision infrastructure for climate-resilient landscape planning (Fathololoumi et al., 2025; Kleinschroth et al., 2022).

This paper demonstrates how UAV technologies bridge ecological monitoring and precision agriculture through a landscape-planning perspective. It includes UAV applications in ecological and land-use monitoring, restoration, and urban contexts, emphasizing methodological progress and challenges. In this concept UAV applications in smart farming, highlighting sensor types, indices, and AI-assisted diagnostics for irrigation, nutrient, and pest management are also included in this paper. This paper also integrates a Mediterranean perspective, including a field-based experiment from Adana, Türkiye, illustrating UAV use in crop stress monitoring under controlled irrigation and nitrogen regimes. In this respect, it discusses integration, standardization, and governance issues, while synthesizing implications for climate-resilient land-use planning.

2. UAVs in Landscape Planning

2.1 Ecological and Land-Use Monitoring

UAVs have revolutionized ecological and land-use monitoring by providing centimeter-scale spatial resolution, flexible revisit capacity, and the ability to integrate multiple sensor modalities. Traditional satellite platforms often face limitations due to cloud cover, coarse pixel size, and fixed revisit times; UAVs bridge these gaps by offering on-demand, ultra-high-resolution data (Sun et al., 2021; Anderson et al., 2025). Their versatility makes them particularly valuable in landscape planning, where small-scale habitat heterogeneity and micro-topographic variation are often decisive for ecological processes.

Habitat mapping is among the most common UAV applications. Digital imagery has been successfully employed to delineate wetland boundaries (Torresan et al., 2020), map riparian buffer zones (Jones et al., 2022), and classify fragmented urban green spaces (Muhmad Kamarulzaman et al., 2023). Using object-based image analysis (OBIA) techniques, UAVs outperform medium-resolution satellite data in distinguishing fine vegetation structures such as invasive species stands, narrow hedgerows, and small water bodies (Franklin & Ahmed, 2018).

Repeated UAV surveys allow monitoring of vegetation succession, land-use intensification, or degradation trajectories at sub-seasonal timescales. UAV-derived spectral indices (e.g., NDVI, NDWI) have been used to assess post-fire recovery (Fernández-Guisuraga et al., 2020), restoration outcomes in grasslands (Jiao et al., 2024), and vegetation monitoring success (van Iersel et al., 2018). High-precision DEMs created by UAV photogrammetry support monitoring of erosion rates in agricultural terraces (Stöcker et al., 2015) and soil loss dynamics in semi-arid regions (Eltner et al., 2016).

UAVs enable monitoring of urban tree canopy health, green roof performance, and vegetation stress during heatwaves (Hu & Minner, 2023; Shao et al., 2021). UAV-derived 3D models of urban parks and squares help planners evaluate shading quality, accessibility, and microclimate regulation. Importantly, these outputs can be linked to ecosystem service assessments, strengthening the evidence base for green infrastructure integration in planning (Berger et al., 2022).

2.2 Restoration, Change Detection & Geomorphic Applications

UAVs are increasingly applied in restoration ecology and geomorphology because they offer fine-scale monitoring of structural and functional indicators critical for assessing intervention success. Restoration projects from wetlands to grasslands and dunes demand accurate baseline mapping, monitoring of treatment areas, and evaluation of ecological trajectories. UAVs, with their ability to generate repeatable 3D and spectral datasets, are now indispensable tools in these contexts (Robinson et al., 2022).

In wetland and coastal restoration, UAVs provide near-real-time monitoring of hydrological dynamics and vegetation colonization. Haskins et al. (2021) showed UAV-derived DEMs achieve centimeter-level vertical accuracy in tidal marsh restoration, enabling volumetric assessments of sediment deposition and erosion. UAV spectral indices have been used to track vegetation regrowth in salt marshes, identify invasive species encroachment, and guide adaptive management of restoration treatments (Török et al., 2021). In dune systems, UAV surveys have been crucial for quantifying dune migration rates, vegetation cover, and stabilization measures (van Iersel et al., 2023).

Change detection at fine scales is another area where UAVs excel. Structure-from-Motion (SfM) photogrammetry allows the generation of sequential DEMs for analyzing geomorphic processes. For example, UAV DEM differencing has been applied to detect landslide movements (Lucieer et al., 2014), riverbank erosion (Cook, 2017), and gully expansion in arid lands (Eltner et al., 2016). UAV thermal and multispectral imagery further enable vegetation health monitoring during restoration, offering early warning signals of stress that might jeopardize project outcomes (Jiao et al., 2024).

In grassland and forest restoration, UAVs are used to assess seedling establishment, monitor canopy closure, and evaluate biodiversity surrogates. Jiao et al. (2024) demonstrated that UAV spectral data can track restoration trajectories in grasslands more accurately than traditional field plots. UAV LiDAR provides additional insights into vegetation structure, detecting vertical growth and canopy stratification crucial for habitat quality assessments (Wallace et al., 2016).

As demonstrated, UAVs enhance the precision, frequency, and transparency of restoration monitoring and geomorphic change detection, but wider adoption requires robust protocols, affordable processing pipelines, and integration into statutory planning frameworks.

2.3 Urban & Mixed Land-Use Planning Applications

The use of UAVs in urban and mixed land-use contexts is rapidly expanding, reflecting growing recognition of the need for fine-scale monitoring of green infrastructure, ecosystem services, and socio-ecological dynamics in cities and peri-urban landscapes. Urban planning demands accurate, up-to-date spatial data on vegetation cover, shading, storm water infrastructure, and land-use transitions domains where UAVs provide actionable insights (Kamarulzaman et al., 2023).

Urban green infrastructure applications include mapping of tree canopy extent, green roof performance, and small-scale vegetation patches often invisible to medium-resolution satellite data. UAV-derived indices such as NDVI and NDRE enable detection of vegetation stress in urban trees, which is essential for proactive maintenance and climate adaptation planning (Hu & Minner, 2023). UAVs are also used to assess shading quality in parks, playgrounds, and plazas, supporting design strategies for urban heat mitigation (Shao et al., 2021).

In peri-urban zones where agriculture, urban expansion, and conservation co-exist, UAVs help delineate land-use boundaries, detect encroachment, and monitor compliance with zoning regulations (Stöcker et al., 2015). UAVs have been applied to assess land fragmentation in rapidly urbanizing areas, offering planners granular evidence for regulating sprawl and protecting ecological corridors (Berger et al., 2022).

Beyond technical mapping, UAVs also play a role in participatory planning and visualization. High-resolution UAV imagery provides intuitive visualizations that serve as 'boundary objects' for negotiation among stakeholders. Kleinschroth et al. (2022) emphasize how UAV imagery enables shared situational awareness in contested landscapes, reducing conflicts and fostering collaboration between planners, residents, and environmental groups.

Recent work integrates UAV outputs into digital twins and 3D urban models, enhancing scenario testing for planners. For example, UAV-based photogrammetry and LiDAR can be merged with GIS to model stormwater runoff, evaluate alternative greening interventions, or visualize densification impacts (Hu & Minner, 2023). This integration supports evidence-based design of resilient urban spaces under climate change.

In conclusion, UAVs extend planners' capacity to assess, design, and engage communities in urban and mixed land-use landscapes. Their role as both analytical and participatory tools makes them indispensable for climate-resilient, inclusive urban planning, though broader institutional frameworks must evolve to mainstream their use.

2.4 Challenges and Gaps

UAVs provide an unprecedented ability to capture fine-scale ecological data for planning, but their integration requires methodological rigor, scaling strategies, and stronger institutional acceptance. Several challenges include:

- scale mismatch (large planning units vs. limited UAV endurance),
- airspace limitations and multi-temporal consistency issues,
- lack of standardized QA/QC,
- Processing burdens, and limited translation of UAV outputs into planning instruments (Villarreal et al., 2025; Anderson et al., 2025).

The scale mismatch between UAV coverage (typically <1 km² per sortie) and landscape planning units (tens to hundreds of km²) demands careful sampling design and multi-scale data fusion (Bazrafkan et al., 2025).

Airspace restrictions in dense cities, privacy concerns regarding UAV imagery of residential areas, and the need for regulatory clarity. Temporal consistency is another hurdle; differences in sun angle, illumination, and vegetation phenology can confound longitudinal analyses (Daniels et al., 2023).

The lack of standardized protocols for radiometric calibration, flight planning, and ground control density limits reproducibility across studies and jurisdictions (Villarreal et al., 2025). UAVs are limited in spatial extent, and repeated surveys require consistent flight paths, radiometric calibration, and illumination correction to avoid spurious change detection (Daniels et al., 2023).

Data-processing demands remain significant, especially for large urban areas where repeated flights generate terabytes of data. The challenge of scaling UAV observations from neighborhood to metropolitan level also persists. The processing demands of multi-temporal datasets, particularly when using LiDAR

or multispectral time series, can also be prohibitive for local NGOs and agencies with limited resources (Stöcker et al., 2015). Furthermore, the translation of UAV-derived indicators into planning-relevant metrics such as restoration success thresholds or compliance measures remains underdeveloped.

3. UAVs in Smart Farming

3.1 Crop Monitoring and Diagnostics

UAV sensing underpins high-resolution crop diagnostics across growth stages by quantifying canopy vigor, water status, nutrient condition, pest/disease onset, and structural traits relevant to management and breeding. Compared with satellite or crewed airborne platforms, UAVs offer on-demand, centimeter-scale acquisitions and flexible revisit, which are critical for catching short-lived stress signals and guiding targeted interventions (Sun et al., 2021; Tanaka et al., 2024; Barathkumar et al., 2024). Crop monitoring and diagnostics may be attributed to below given topics and considerations:

- Sensing modalities and variables to measure
- Physiological proxies and indices
- From pixels to decisions: Machine and deep learning (ML/DL) diagnostics
- Fusion and scaling
- Uncertainty, validation, and radiometry
- Operational considerations

RGB imaging capabilities of UAVs provide various sensing modalities by which many variables such as crop vigor can be measured and mapped. Multispectral imagery enables NDVI/NDRE metrics tied to chlorophyll/nitrogen; thermal sensing captures canopy temperature for water stress (CWSI); LiDAR provides canopy structure. Integration of datasets (e.g. fusion) improves diagnostic accuracy (Alves et al., 2024; Zhang et al., 2025; Dong et al., 2024; Araújo-Paredes et al., 2022; Lacerda et al., 2022; Yewle et al., 2025).

Indices such as NDVI, NDRE, SAVI, NDWI, and CWSI are key. Best practice emphasizes index choice tailored to crop/phenology, use of red-edge for high-LAI conditions, fusion of thermal and spectral data, and rigorous ground validation (Dong et al., 2024; Tanaka et al., 2024).

While machine and deep learning automate disease, nutrient, and yield prediction with accuracies over 90%, some challenges such as domain shift and label scarcity still exist. Emerging methods include on-edge inference and federated learning for privacy-preserving deployment (Agrawal & Arafat, 2024; Guebsi et al., 2024; Anam et al., 2024; Zhu et al., 2024; Yewle et al., 2025).

UAV–satellite fusion extends diagnostics to regional scales. Models trained on UAV data calibrate satellite series for wall-to-wall monitoring. Ground validation remains essential (Bazrafkan et al., 2025; Bongomin et al., 2024; Tanaka et al., 2024).

Radiometric calibration and illumination correction are also critical. Some models such as Empirical Line Method with reference panels reduces bias. Downwelling light sensors have the ability to improve stability. SOPs should specify flight time, sun angle, and quality assurance/quality control (QA/QC) steps (Daniels et al., 2023; Swaminathan et al., 2024a, 2024b; Didan et al., 2023).

Key practices include timing flights to phenological stages, avoiding adverse weather, and nesting UAV monitoring within tiered designs (UAV–satellite–ground). Participatory visualization helps translate diagnostics into planning instruments (Bongomin et al., 2024; Kleinschroth et al., 2022).

3.2 Irrigation & Nutrient Management

UAVs have become central to water- and nutrient-efficient agriculture because they connect plant-level physiology to actionable management zones. Thermal imaging enables estimation of canopy temperature and the Crop Water Stress Index (CWSI), which proxies short-term water status and supports variable-rate irrigation (VRI) scheduling at sub-field scales (Dong et al., 2024; Yadav et al., 2024). When thermal data are fused with multispectral red-edge indices (NDRE) that track chlorophyll and nitrogen status, practitioners can separate transient heat effects from chronic nutrient limitations, improving the specificity of irrigation vs. fertilization decisions (Tanaka et al., 2024; Wang et al., 2024). Repeated flights across key phenological windows pre-flowering, grain fill, or fruit enlargement capture stress trajectories otherwise missed by weekly satellite revisit, and support irrigation timing and dose optimization under water scarcity (Yadav et al., 2024).

Nutrient management leverages spectral–physiological linkages between leaf chlorophyll/N and red-edge reflectance. UAV multispectral products (NDRE, MCARI derivatives) and even calibrated RGB surrogates (e.g., VARI) can detect within-field variability in crop vigor that correlates with N deficiencies, guiding zone-specific fertilizer applications and reducing runoff (Alves et al., 2024; Zhang et al., 2025). In perennials (e.g., olives and orchards), flights timed to post-flowering and post-veraison stages capture persistent nutrient limitations manifested as canopy chlorosis and thinning; these data have been linked to site-specific foliar feeding or banded ground applications to minimize waste (Greco et al., 2025; Hnida et al., 2025).

UAV sprayers are advancing, with innovations in droplet size, path planning, and nozzle design reducing drift and improving efficiency (Delavarpour et al., 2023; Farid et al., 2024). Spot spraying and multi-UAV coordination support precision and safety near sensitive ecosystems.

For Mediterranean systems, where water scarcity and salinity co-occur, UAV-derived NDWI and thermal CWSI jointly map irrigation need and potential salinity hotspots, informing blended freshwater–brackish rotations and deficit-irrigation strategies at parcel edges.

Analytics increasingly combine multimodal predictors thermal, red-edge, canopy height (LiDAR), and weather covariates inside machine-learning or hybrid process–learning models to predict crop evapotranspiration (ETc) and site-specific irrigation setpoints (Fathololoumi et al., 2025; Yewle et al., 2025). Such models outperform single-sensor regressions and allow planners to upscale field insights by training satellite time series with dense UAV labels (Bazrafkan et al., 2025). However, robust performance depends on radiometric calibration (empirical line with panels, downwelling sensors), consistent sun–target geometry, and rigorous ground truth (leaf water potential, sap flow, soil moisture), otherwise bias propagates into prescriptions (Daniels et al., 2023; Swaminathan et al., 2024a, 2024b).

Socio-technical barriers also persist. VRI hardware, telemetry, and skilled analytics are cost-intensive for smallholders; institutional programs or cooperative service models can distribute costs and build capacity (Guebsi et al., 2024; Aliloo et al., 2024). From a planning perspective, the landscape implication is substantial: if UAV-guided irrigation and nutrient zoning stabilize yields on existing farmland, expansion pressure on sensitive habitats (dunes, wetlands, riparian buffers) can be reduced aligning farm efficiency with landscape-level conservation targets (Kleinschroth et al., 2022; Villarreal et al., 2025).

3.3 Integration with AI, Internet-of-Things (IoT) & Robotics

The synergy of UAVs with AI and Internet-of-Things (IoT) systems enables smarter decision loops. Tsouros et al. (in Tsouros et al. 2019 review) highlight that UAV + IoT frameworks support real-time monitoring and decision-making across crop cycles. Some experimental systems combine UAVs and ground robots (UGVs). For example, the "Flourish" project developed a hybrid aerial-ground robotics system: UAVs scout and identify weed or stress zones, UGVs have the capability to apply treatments locally (Pretto et al., 2020). UAVs increasingly work within IoT frameworks and hybrid systems with ground robots (Pretto et al., 2020). This integration supports real-time monitoring and site-specific interventions, enhancing sustainability of farm practices.

3.4 Challenges and Socioeconomic Barriers

Adoption is constrained by high costs, lack of skills, limited standardization, regulatory complexity, and equity concerns. Environmental issues (wildlife disturbance, e-waste) and digital divides further complicate deployment (Aliloo et al., 2024; Narzari et al., 2025). Despite above mentioned technical promise, deployment is uneven due to the following:

- Cost & threshold scale: For smallholders, the cost of UAVs and sensors is often prohibitive (Guebsi et al., 2024; Narzari et al., 2025).
- Skills and capacity: Data processing, model training, and calibration require specialized skills many farmers lack.
- Standardized workflows: As with landscape planning, UAV workflows (flight design, calibration) are fragmented and often bespoke (Tsouros et al.; Guebsi et al., 2024).
- Regulatory, liability & data privacy: UAV operations face airspace rules, liability risks, and concerns about capturing images over private land (Narziari et al., 2025).
- Environmental and equity concerns: Issues like e-waste, wildlife disturbance, and unequal access between large-scale and small-scale farms are emerging debates (Narziari et al., 2025).

3.5. UAV Applications in the Mediterranean and the Case of Adana

UAVs are increasingly applied in olive, citrus, and aromatic plant systems In the Mediterranean region. For example, UAV-based NDVI and thermal indices have been used to optimize irrigation scheduling in olive orchards under water-limited conditions, improving efficiency without yield losses (Greco et al., 2025). In aromatic plants (rosemary, sage), UAV-derived vigor maps helped guide harvest timing, quality indexing, and microclimate assessments (Greco et al., 2025). Recent experimental work in UAE palm cultivation showed that low-cost RGB-based indices (e.g., VARI, MGRVI) rival multispectral indices for classifying vegetation stress, reducing system cost (Panthakkan et al., 2025). These case studies underscore the dual role of UAVs: improving farm-level productivity while offering precinct-level geospatial inputs to regional planners (reducing agricultural encroachment on fragile ecosystems).

A representative regional example is provided by the Çukurova University UAV-based Smart Farming Experiment (Adana, Türkiye), conducted within an approximately one-hectare experimental field established in 2024-2025. The experiment aimed to quantify the effects of irrigation and nitrogen treatments on wheat performance using UAV multispectral and thermal imagery.

A total of 90*90m field was used. Parcel size was 6*10m and the spacing between parcels was set as 3m. Also a three-meter buffer was applied around the experimental fields to protect the experiment from external factors such as seeding. In terms of representing seasonal differences, early- and late-crop applications were designed. The field was divided into 54 experimental plots arranged in a factorial block

design combining three irrigation levels (0, 50, and 100%) with three nitrogen rates (0, 10, and 20 g/m²) (Figure 1).



Figure 1. Experimental fields to quantify the effects of irrigation and nitrogen treatments on wheat performance using UAV multispectral and thermal imagery.

UAV flights were carried out five times between April and June 2025 using 10-band multispectral sensors, generating approximately 2,700 images (Figure 2). Derived vegetation indices (NDVI) and thermal-based Crop Water Stress Index (CWSI) revealed consistent spatial gradients linked to irrigation and nutrient status, validated by ground-based measurements.

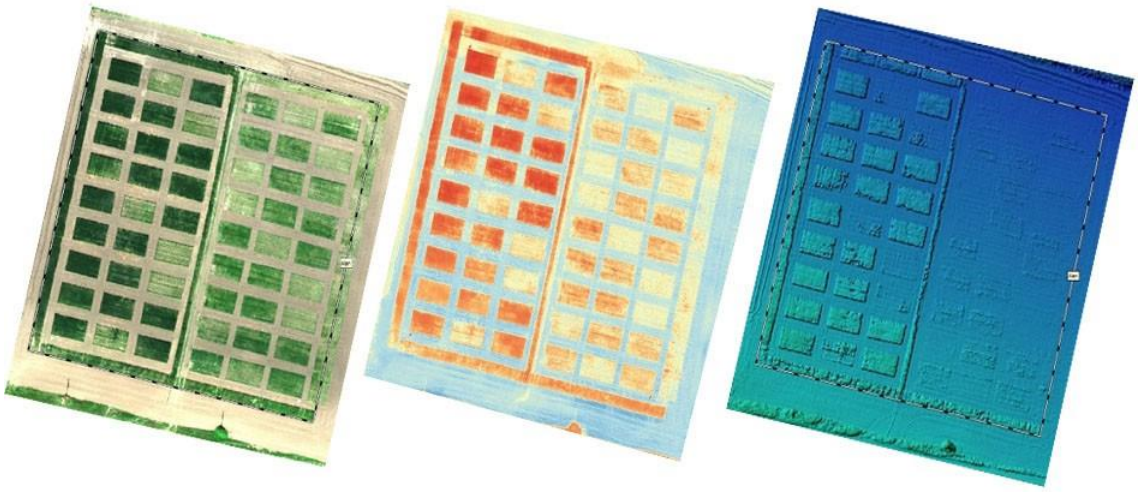


Figure 2. Sample Mosaicked Multispectral UAV Images of The Study Area

Results indicated that UAV-derived indices effectively distinguished water- and nutrient-stress conditions in Mediterranean wheat systems, confirming their applicability for fine-scale irrigation scheduling and yield prediction. Despite challenges related to cloud cover, wind, and drought-induced data gaps, the Adana experiment underscores UAVs' role in operationalizing smart farming under semi-arid conditions while supporting regional planning to balance agricultural productivity and ecosystem resilience.

These findings, combined with regional examples from olive and aromatic crop systems, demonstrate how UAV-based approaches can serve as transferable frameworks for Mediterranean agro-landscapes where water scarcity, soil salinity, and habitat pressures converge.

5. Integration, Challenges & Future Directions

Translating UAV insights into planning instruments is an essential element for landscape planning. Thus a core lacuna in the literature is how UAV-derived metrics become legible to planners. For instance, conversion of a biomass map or soil moisture anomaly into zoning thresholds or restoration targets is always challenging. Therefore, the research efforts must focus on indicator translation, rulesets, and decision-support tools bridging sensors and statutory plans.

Multi-scale fusion and scaling is generally necessary to increase the efficiency of UAV-derived data. To inform regional planning, UAV outputs must be fused with satellite and airborne data. Some machine learning techniques such as training satellite-based vegetation indices with UAV-derived ground truth (Mazzia et al., 2020) are promising. Scaling approaches must ensure consistency across scales. Standardization and open protocols are necessary to enhance reproducibility and regulatory acceptability. In this respect, the community needs to converge on open, shared UAV protocols (flight, calibration, quality assurance/control). Some authors (Villarreal et al., 2025; Anderson et al., 2025) call for PRISMA-style metadata standards for UAV studies.

UAV-based imagery (orthomosaics, 3D models) serve as intuitive tools in participatory planning. Embedding UAV-based scenario visualization in planning workshops, and public engagement can help planners and communities negotiate tradeoffs more effectively (Kleinschroth et al., 2022). UAV systems must align with sustainability and equity goals. This includes reducing digital divides (ensuring smallholders can access UAV tools), minimizing environmental externalities (e-waste, wildlife disturbance), and designing governance regimes (data sovereignty, privacy, liability) that foster trust and legitimacy (Narziari et al., 2025).

6. Conclusion

UAVs are increasingly recognized as dual-purpose tools: at the farm scale they enable smart farming via optimized inputs and diagnostics, and at the landscape scale they provide planners with actionable ecological data. By bridging these scales, UAVs hold transformative potential for climate-resilient planning and sustainable agriculture.

This paper has demonstrated that UAVs are not merely experimental tools but are rapidly becoming integral components of landscape planning and smart farming systems. Their capacity to deliver ultra-high-resolution, on-demand data enables planners, agronomists, and decision-makers to monitor ecological dynamics, diagnose crop health, and implement precision interventions that enhance both productivity and environmental stewardship.

Looking ahead, smart farming applications are expected to become widespread in the near future, driven by continued advances in UAV hardware, sensors, analytics, and integration with AI. Agricultural landscapes stand to benefit substantially from these innovations. UAV-based irrigation and nutrient diagnostics will ensure that water use is minimized, aligning agricultural practices with increasingly scarce freshwater resources. Similarly, nutrient and chemical loads will be optimized, reducing input

waste, cutting production costs, and mitigating the risk of leaching and runoff. This will translate into less eutrophication of water bodies and lower contamination of soils and groundwater.

Equally important, UAV systems linked with ground-based monitoring and AI analytics will enable continuous surveillance of pollution pathways and ecosystem responses, allowing early detection of stress in riparian buffers, wetlands, and dune ecosystems. Such monitoring supports adaptive management and can strengthen compliance with environmental regulations. In peri-urban mosaics, UAV-enabled smart farming may further buffer natural habitats from expansion pressures by stabilizing yields and improving efficiency within existing farmland.

From a planning perspective, the implications extend beyond the field scale. If adopted at scale, UAV-driven smart farming can contribute to landscape-level sustainability, where agricultural intensification is decoupled from environmental degradation. By improving water and nutrient efficiency, reducing chemical dependency, and enabling transparent reporting of land management practices, UAV applications strengthen the integration of agricultural production with conservation and climate adaptation goals.

In conclusion, UAVs are poised to reshape the governance of agricultural landscapes by enabling a transition toward climate-resilient, resource-efficient, and ecologically attuned farming systems. Their widespread adoption will not only improve farm-level productivity but also safeguard ecosystem services and biodiversity core objectives for sustainable landscape and urban planning in the coming decades.

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