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UAV-BASED THERMAL AND MULTISPECTRAL MONITORING OF POTENTIAL IRRIGATION-RELATED ANOMALIES IN SURFACE AND SUBSURFACE DRIP-IRRIGATED POTATO

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Abstract. *Drip irrigation efficiency may be reduced by emitter clogging caused by sediment accumulation, soil intrusion, fertigation-related deposits or manufacturing defects. These problems can generate spatially heterogeneous water availability and crop responses, particularly in subsurface irrigation systems. This study aims to assess the potential of UAV-based thermal and multispectral imagery to map anomalies potentially associated with irrigation-related water deficits in surface and subsurface drip-irrigated potato (Solanum tuberosum L.). The experimental areas will comprise approximately 1,500 m² of surface drip irrigation and 2,000 m² of subsurface drip irrigation. A DJI Matrice 300 RTK equipped with a Zenmuse H30T thermal camera and a CHNSpec FS-500 multispectral sensor will be used for repeated aerial surveys. Thermal imagery will be analysed to identify spatial variations in apparent surface and canopy temperature, while multispectral imagery will support the calculation of vegetation indices, including NDVI, NDRE and GNDVI. Image acquisition is planned at one week intervals and following selected irrigation or treatment events, using consistent flight parameters and comparable observation conditions. The analysis will investigate the spatial and temporal consistency of thermal and spectral anomalies and compare their distribution between the two irrigation systems. Particular attention will be given to the differences between surface-visible soil responses and indirect vegetation responses above buried irrigation lines. As the assessment will rely exclusively on airborne data, detected anomalies will be interpreted as potential indicators of irrigation-related water deficits rather than confirmed emitter malfunctions. The study will evaluate the feasibility and limitations of UAV-based multisensor monitoring as a non-invasive screening approach for identifying areas requiring further irrigation system inspection.*

Keywords*: UAV; multispectral imagery; drip irrigation; emitter clogging; potato cultivation.*

INTRODUCTION

Efficient irrigation management is essential for maintaining agricultural productivity and ensuring the sustainable use of water resources under increasingly variable climatic conditions. In Western Romania, irregular rainfall and seasonal water deficits can limit crop development and increase the need for supplementary irrigation (ȘMULEAC et al., 2023; ȘMULEAC et al., 2024). Recent research conducted at the University of Life Sciences "King Mihai I" from Timișoara has also highlighted the potential of integrating remote sensing and hydrological modelling to assess irrigation practices, soil moisture dynamics and crop health (VASILONI et al., 2025). In this context, identifying irrigation system malfunctions at an early stage could improve water distribution, reduce unnecessary water losses and support more precise agricultural management.

Drip irrigation is widely used to deliver water directly to the crop root zone, but its performance depends on the uniformity and reliability of the emitters. Emitter clogging can result from physical particles and sediment, chemical precipitation, fertilizer-related deposits and biological growth. Interactions between these factors may further increase the risk of obstruction, particularly when water quality and fertigation management are inadequate (LIU et al., 2022; SHEN et al., 2022; RAMACHANDRULA and KASA, 2022; WANG et al., 2025). Soil particle

intrusion, local damage and manufacturing variability may also contribute to abnormal emitter discharge. These problems can produce uneven water application and localized soil moisture deficits, potentially affecting crop development. The severity of clogging depends on emitter design, water characteristics and operating conditions, while the effectiveness of available prevention and maintenance measures varies with the underlying mechanism (PEREIRA et al., 2020; SHI et al., 2023).

The detection of emitter malfunction remains a practical challenge because the affected components are small and may be difficult to inspect, particularly in subsurface drip irrigation systems. Conventional assessments rely on hydraulic measurements, including emitter discharge, operating pressure and irrigation distribution uniformity. Although these measurements provide essential evidence of system performance, they may require considerable field effort and do not always reveal the spatial extent of an emerging problem. PETIT et al. (2022) identified the limitations of existing approaches for directly detecting emitter clogging under field conditions. Consequently, complementary methods capable of locating areas requiring further inspection could improve irrigation system monitoring without replacing hydraulic verification.

Unmanned aerial vehicles (UAVs) equipped with multispectral sensors provide high-resolution imagery that can reveal spatial differences in crop condition across agricultural plots. Vegetation indices derived from visible, red-edge and near-infrared bands, including the Normalized Difference Vegetation Index (NDVI), Normalized Difference Red Edge Index (NDRE) and Green Normalized Difference Vegetation Index (GNDVI), can be used to assess variations in canopy development and vegetation response. UAV-based remote sensing has demonstrated potential for monitoring crop water stress, although detection performance depends on crop type, growth stage, sensor characteristics and environmental conditions (SHARMA et al., 2025). Research on potato has also shown that remotely sensed spectral information can support the assessment of canopy water status, while the interpretation of vegetation indices varies throughout crop development. Related studies using multispectral and thermal imagery in sweet potato have further demonstrated the value of repeated aerial observations for characterizing crop responses to water deficit (RAMÍREZ et al., 2023).

Thermal remote sensing offers a complementary approach because canopy temperature can provide information about plant water stress. Previous investigations have evaluated thermal indicators for potato irrigation scheduling and water status assessment, while multispectral and thermal measurements have also been used to monitor crops under subsurface irrigation (RUD et al., 2014; RINZA et al., 2022; ZÚÑIGA ESPINOZA et al., 2017). Related work has investigated infrared techniques for detecting water leakage in drip irrigation systems (TÜRKLER et al., 2023). UAV-based visible, multispectral and thermal imagery has additionally shown potential for mapping subsurface agricultural drainage infrastructure, although spatial patterns may be confused with other field features (ALLRED et al., 2020). Nevertheless, these approaches do not establish that spectral or temperature anomalies can independently identify emitter clogging or determine its cause. Such anomalies must be interpreted alongside field measurements of soil moisture and hydraulic performance.

The present study aims to assess the potential of UAV-based multispectral imagery to identify spatial patterns associated with emitter-related water deficits in surface and subsurface drip-irrigated potato (*Solanum tuberosum* L.). The experiment will cover approximately 1,500 m² of surface drip irrigation and 2,000 m² of subsurface drip irrigation, using a DJI Matrice 300 RTK equipped with a CHNSpec FS-500 multispectral sensor. Repeated image acquisitions, planned at approximately two-week intervals and following selected experimental treatments,

will be used to investigate the spatial and temporal development of vegetation anomalies. The spectral observations will be compared with independent measurements of emitter discharge, operating pressure and soil moisture. The central hypothesis is that persistent reductions in emitter performance can produce spatially coherent crop responses that may be detected through multispectral imagery, with detection performance potentially differing between surface and subsurface systems. The study will evaluate the feasibility of UAV-based multispectral monitoring as a non-invasive screening method for prioritizing field inspections, rather than as a substitute for direct diagnosis of irrigation system defects.

MATERIAL AND METHODS

Study Area and Research Design

The study will be conducted on potato (*Solanum tuberosum* L.) plots in Timișoara, western Romania. The monitored area will total approximately 3,500 m²: 1,500 m² under surface drip irrigation and 2,000 m² under subsurface drip irrigation. Planting is planned for late March or early April. The four cultivars are Bellarosa, Carrera, Redsec and Brașovia; however, the main focus is technical monitoring of irrigation-related spatial anomalies rather than cultivar performance.

An exploratory observational design based exclusively on repeated UAV imagery will be used. No defects will be deliberately introduced, and no ground-based soil-moisture, flow or pressure measurements will be collected. The locations of both irrigation systems and cultivated areas will be delineated in a georeferenced plot map. Since only one main plot is available for each irrigation configuration, differences between systems will be interpreted descriptively rather than as independently replicated experimental effects.

Irrigation Schedule and Water Application

Both plots will follow a nominal irrigation schedule of 45 mm every seven days. Assuming uniform application, the theoretical volume will be 67.5 m³ for the surface-irrigated plot and 90 m³ for the subsurface-irrigated plot, or 157.5 m³ per cycle in total. These are calculated volumes, not independently measured discharge values.

UAV surveys will also take place weekly, approximately 24 hours before the next irrigation, or around six days after the previous event. The irrigation schedule and time since the last irrigation will be recorded for each survey and considered when interpreting thermal and multispectral patterns. The planned application depth does not demonstrate that water is distributed uniformly across either plot.

UAV Platform and Sensor Configuration

Image acquisition will use a DJI Matrice 300 RTK equipped with a DJI Zenmuse H30T thermal camera, a CHNSpec FS-500 multispectral camera and a DJI Zenmuse P1 RGB camera. The H30T uses an uncooled vanadium oxide microbolometer operating in the 8–14 μm range and produces 1280 × 1024 radiometric JPEG (R-JPEG) thermal images. Temperature extraction will use compatible software, such as DJI Thermal Analysis Tool 3 (DTAT3).

The FS-500 records bands centred at 555 nm (green), 660 nm (red), 720 nm (red-edge) and 840 nm (near-infrared), as well as RGB imagery. Its multispectral images are provided in 16-bit TIFF format. The Zenmuse P1 may provide supplementary RGB mapping to delineate crop rows, canopy gaps and visible surface features (DJI Enterprise, n.d.; CHNSpec, n.d.). Because the H30T and FS-500 are separate payloads, they will be flown separately, with acquisitions scheduled as close together as practicable.

UAV Flight Planning and Image Acquisition

Surveys will be conducted every seven days from an initial reference flight throughout the potato growing season. The nominal flight altitude will be 50 m above ground level (AGL). Flights will be planned for comparable daytime conditions, with an initial image overlap of approximately 80% forward and 70% side overlap; these settings may be adjusted after a pilot flight according to image coverage and processing quality. Flight altitude, direction, overlap, acquisition time and other relevant parameters will be recorded for each campaign.

Thermal and multispectral surveys will preferably occur within the same observation window under relatively stable conditions. Flights will be avoided immediately after rainfall and when the canopy is wet. The planned timing—approximately 24 hours before the next irrigation—will help standardize the interval since watering. Original imagery, flight logs and image metadata will be retained for each survey. RTK positioning will support georeferencing and alignment between dates; no ground control points will be installed.

Thermal Image Processing and Analysis

H30T images will be processed from the original R-JPEG files using DTAT3 or equivalent software capable of extracting radiometric temperature information. High Gain mode will be used for quantitative temperature assessment, while High-Resolution mode will not be used for this purpose because it does not support temperature measurement (DJI Enterprise, n.d.). Emissivity, target distance and available atmospheric settings will be recorded and kept consistent where possible.

Where image quality and canopy cover permit, exposed soil and vegetated surfaces will be analysed separately. Surface drip irrigation may produce local soil-temperature patterns associated with wetting and evaporation, whereas subsurface irrigation may affect canopy temperature indirectly through plant water status. These patterns will be treated as potential indicators, not direct confirmation of emitter malfunction (CUCHO-PADIN et al., 2020; MESSINA and MODICA, 2020).

For each survey, apparent-temperature distributions will be summarized using the median, interquartile range and the extent of relatively warm or cool areas. Thermal mosaics will be produced only if the workflow preserves quantitative radiometric information; otherwise, georeferenced thermal frames will be compared individually using spatially aligned regions.

Multispectral Processing and Vegetation Indices

FS-500 16-bit TIFF images will be processed using the manufacturer's workflow. Spectral bands will be aligned, and available radiometric or reflectance-processing procedures will be applied consistently. As the availability of an independent reflectance calibration panel has not been established, the analysis will emphasize within-date spatial variation and relative temporal changes rather than assuming absolute reflectance comparability between dates.

Three indices will be calculated from the available bands:

- Normalized Difference Vegetation Index (NDVI): NDVI = (NIR − Red) / (NIR + Red)
- Normalized Difference Red Edge Index (NDRE): NDRE = (NIR − RedEdge) / (NIR + RedEdge)
- Green Normalized Difference Vegetation Index (GNDVI): GNDVI = (NIR − Green) / (NIR + Green)

These indices will characterize spatial differences in canopy greenness and spectral response. Vegetated areas will be separated from exposed soil and other non-vegetated surfaces using RGB imagery and spectral information. This is particularly important during early growth, when soil contributes substantially to the observed signal. Seasonal changes in canopy cover will

be considered during comparisons. The indices will be treated as indirect indicators of crop response, not direct measurements of soil moisture, irrigation discharge or emitter clogging.

Spatial Anomaly Detection and Multisensor Integration

Thermal and multispectral datasets will be georeferenced and aligned to compare corresponding locations within each plot. The analysed area will provisionally be divided into 1 × 1 m cells, subject to confirmation against ground sampling distance, image quality and crop-row geometry. This common spatial unit will support comparison without treating individual pixels as independent observations.

Thermal anomalies will be defined as locations with relatively higher or lower apparent temperatures than their immediate surroundings in the same survey. Multispectral anomalies will be identified from locally unusual vegetation-index values. Robust anomaly scores based on the median and median absolute deviation may be used for exploratory screening; an initial threshold of approximately two robust standard deviations may be tested but will not be treated as a validated diagnostic limit.

The integrated analysis will distinguish thermal-only, multispectral-only and spatially coincident thermal–multispectral anomalies. Their area and persistence will be tracked across weekly surveys. Outputs will include georeferenced maps, the percentage of the analysed area classified as anomalous, descriptive statistics for temperature and vegetation indices, and temporal profiles. The plots will first be analysed separately and then compared descriptively.

Methodological Limitations

The study will use only UAV-derived thermal, multispectral and, where needed, RGB imagery. Without independent measurements of soil moisture, emitter discharge, pressure or distribution uniformity, the analysis cannot confirm specific malfunctions or establish detection accuracy. Anomalies may also reflect soil variation, crop development, canopy density, nutrition, shading or environmental conditions. Differences between the two plots may therefore arise from site-specific factors as well as irrigation configuration. Findings will be interpreted as an exploratory assessment of UAV-based multisensor screening to identify areas that may warrant further inspection, not as a confirmed diagnosis of irrigation defects.

RESULTS AND DISCUSSIONS

Planned monitoring context and calculated irrigation volume

The planned monitoring campaign covers two potato plots: 1,500 m² under surface drip irrigation and 2,000 m² under subsurface drip irrigation. Both plots are scheduled to receive a nominal irrigation depth of 45 mm at seven-day intervals, with weekly UAV surveys at 50 m above ground level, ideally approximately 24 hours before the next irrigation event. The sensor payloads provide complementary image products: radiometric thermal imagery from the DJI Zenmuse H30T and multispectral imagery from the CHNSpec FS-500. The FS-500 records bands centred at 555, 660, 720 and 840 nm, enabling calculation of GNDVI, NDVI and NDRE (DJI Enterprise, n.d.; CHNSpec, n.d.).

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Table 1

Planned monitoring configuration

Parameter	**Surface drip plot**	**Subsurface drip plot**
Planned area	1,500 m²	2,000 m²
Irrigation configuration	Drip lines at soil surface	Drip lines buried below soil surface
Nominal application depth	45 mm per event	45 mm per event
Irrigation interval	7 days	7 days
UAV survey interval	7 days	7 days
Nominal flight altitude	50 m AGL	50 m AGL
Primary image products	H30T thermal; FS-500 multispectral	H30T thermal; FS-500 multispectral
Ground validation	Not planned	Not planned

The nominal applied-water volume is calculated as plot area multiplied by application depth expressed in meters. A 45 mm application corresponds to 0.045 m; therefore, the planned volume is 67.5 m³ for the surface-irrigated area and 90.0 m³ for the subsurface-irrigated area. The combined nominal volume is 157.5 m³ per irrigation event. These are theoretical quantities derived from the planned application depth and mapped area; they are not measurements of the delivered water volume or evidence that the applied water is distributed uniformly.

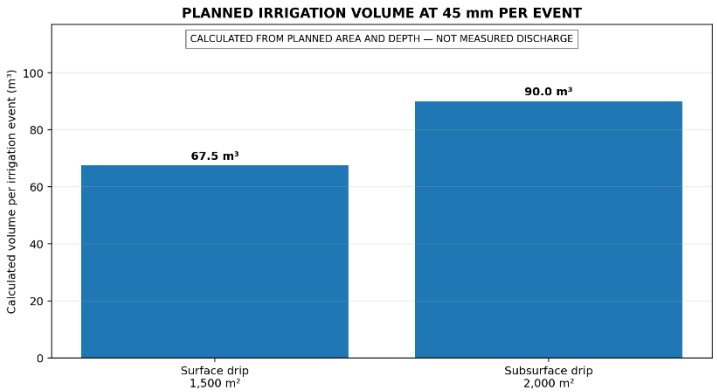


Figure 1. Calculated irrigation volume per planned event. Values are calculated from area × 0.045 m; they are not measured flow or application uniformity.

Thermal and multispectral image products

Figure 2 presents an aerial scene arranged to illustrate the types of visual products that are produced during the study: a visible/RGB-like overview, a thermal-style view, a false-colour vegetation view and a candidate anomaly overlay. The image is an aerial photograph of the experimental field, was captured by the Zenmuse H30T and FS-500, and contains radiometrically calibrated measurements.

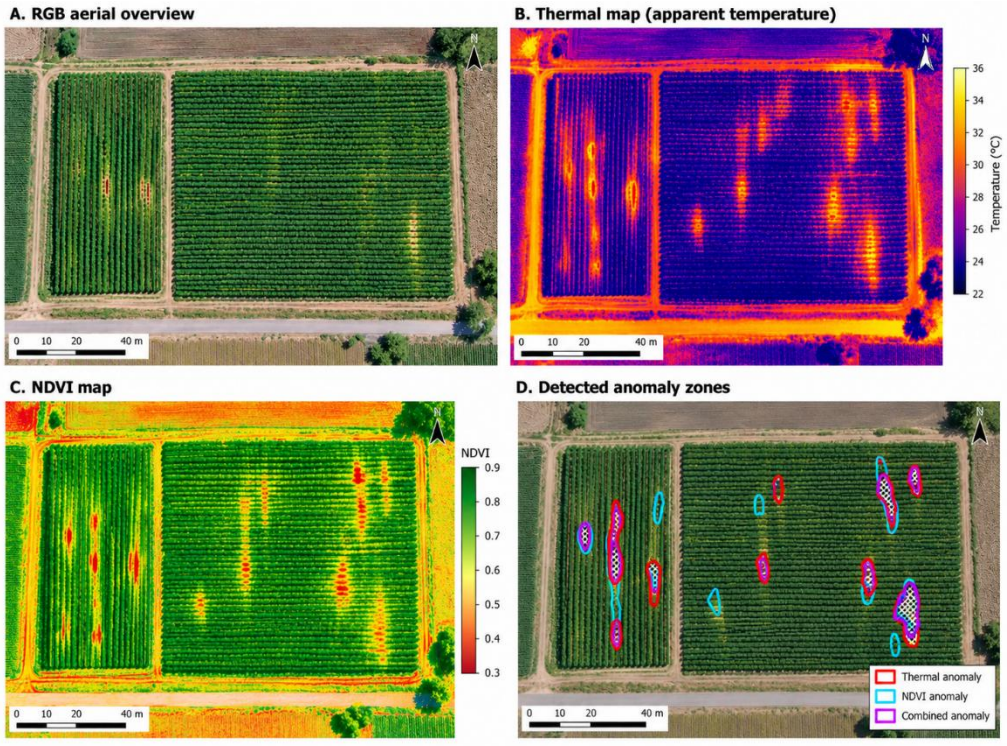


Figure 2. Visual of UAV output

Figure 3 shows a separate raster example in which warm patches are paired with low-NDVI patches at selected locations. This is an example of how candidate anomalies can be visualized after image processing and co-registration. In the actual study, the anomaly pattern must emerge from the acquired sensor data rather than being specified in advance. The temperature anomaly scale is relative; it is a Zenmuse H30T temperature product. Similarly, the NDVI surface is derived from FS-500 imagery.

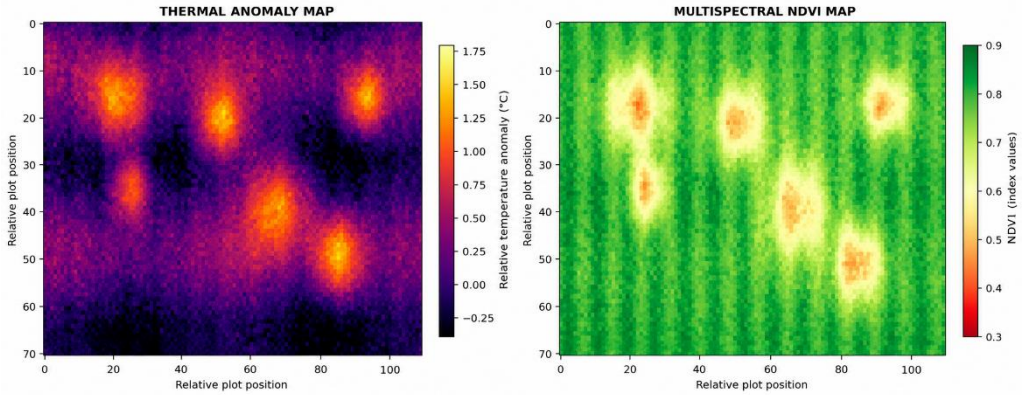


Figure 3. Thermal-anomaly and NDVI maps used to demonstrate the spatial analysis

Temporal analysis of candidate anomalies

Weekly observations will be used to determine whether mapped anomalies persist, change in extent or disappear across successive surveys. For a candidate region, the thermal contrast (ΔT) will be calculated as the median temperature of the candidate region minus the median temperature of a nearby reference region. The spectral contrast (ΔNDVI, ΔNDRE or ΔGNDVI) will be calculated using the same candidate and reference areas. The reference region should be selected within the same plot and, where possible, within a comparable crop-growth and illumination context.

The proportion of the plot identified as anomalous will be calculated as the number of flagged valid analysis cells divided by the total number of valid cells, multiplied by 100. The temporal persistence of an anomaly will be expressed as the percentage of valid survey dates on which a spatially corresponding anomaly is present. Cross-sensor overlaps can be summarized using the intersection-over-union of the thermal and multispectral anomaly masks. Without independent ground truth, these metrics describe image-derived patterns and sensor agreement rather than diagnostic accuracy.

Table 2

Interpretation framework for aerial anomaly patterns

Observed image pattern	**Possible interpretation**	**Important alternative explanations**
Relatively warm canopy + locally lower NDVI/NDRE, persisting across flights	Candidate area of irrigation-related water deficit	Nutrient stress, disease, cultivar differences, soil variability or phenological differences
Warm surface patch visible in exposed soil, without canopy anomaly	Difference in soil wetness, evaporation or surface properties	Soil texture, shading, recent rainfall or variable solar exposure
Lower vegetation index without a clear thermal anomaly	Change in canopy development or vegetation condition	Plant gaps, disease, nutrient limitation, senescence or mixed soil-canopy pixels
Cool surface patch without a corresponding canopy response	Possible recent wetting or a local surface-energy difference	Shade, damp soil from rainfall, drainage or emissivity differences
Anomaly follows a row or a suspected lateral over multiple dates	Spatial pattern worth prioritizing for inspection	Row geometry, planting variability or repeated soil/canopy differences; not proof of a clogged emitter

The distinction between the two irrigation configurations is important. With surface drip irrigation, local soil-surface cooling or moisture-related patterns may be visible when soil is exposed between plants. In subsurface drip irrigation, the buried lateral cannot be observed directly; any signal at the surface is more likely to be indirect and mediated by soil heat transfer and plant response. As the canopy closes, thermal and spectral observations increasingly represent the vegetation rather than the soil. Consequently, the interpretation should be conditioned on crop development, canopy cover, time since irrigation and image-acquisition conditions.

Persistence across weekly surveys

Figure 4 demonstrates how relative thermal and multispectral signals are across eight weekly surveys. The plotted values are created to illustrate the reporting format: the example candidate area becomes progressively warmer relative to its local reference, while its NDVI difference becomes more negative. This pattern is plausible as a hypothesis for testing, but it is not an outcome of the planned experiment.

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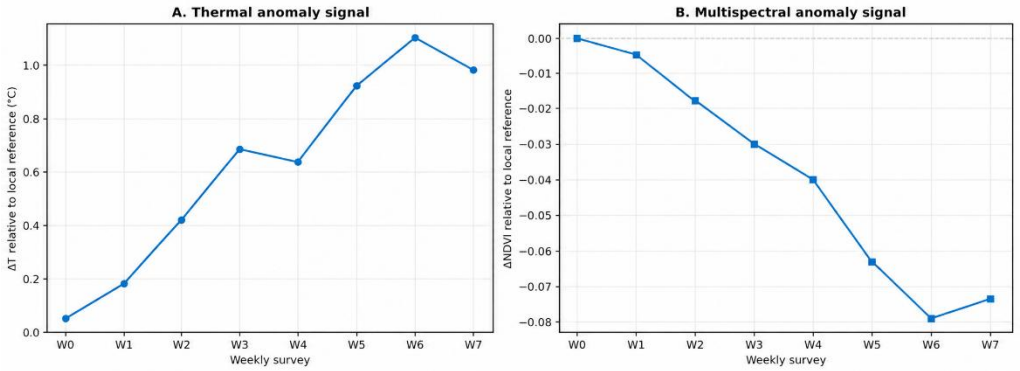


Figure 4. Candidate-anomaly persistence using weekly values. ΔT and ΔNDVI

In the field dataset, persistence could be quantified as the number or proportion of consecutive survey dates on which a candidate anomaly remains present. Spatial agreement between the thermal and multispectral layers could be summarized using the intersection-over-union of their mapped anomaly regions or the percentage of anomalous cells detected by both sensors. These indicators describe temporal consistency and cross-sensor agreement; without independent ground truth, they must not be interpreted as sensitivity, specificity or overall detection accuracy.

Table 3

Proposed image-derived indicators for the final field analysis

Indicator	**Definition**	**Interpretation**
Thermal difference, ΔT	Median T(candidate) − median T(reference), °C	Thermal contrast; not direct stress measurement
Spectral difference, ΔVI	Median VI(candidate) − median VI (reference)	Relative canopy spectral contrast
Anomalous area (%)	Anomalous cells / valid cells × 100	Share of plot flagged by the chosen threshold
Temporal persistence (%)	Surveys with recurring anomaly / valid surveys × 100	Repeatability across survey dates
Cross-sensor overlap (IoU)	Area intersection / area union of the two anomaly masks	Spatial agreement, not diagnostic accuracy

Discussion, limitations and reporting requirements

The principal contribution of the proposed analysis is the integration of radiometric thermal and multispectral imagery into a repeated spatial-monitoring workflow. Thermal information may indicate differences in apparent canopy temperature, while vegetation indices provide complementary information about the spatial variability of crop condition. Previous work has demonstrated the relevance of infrared thermography for monitoring water status in potato, including UAV-oriented processing approaches (CUCHO-PADIN et al., 2020). These studies support the rationale for testing a combined workflow, but they do not establish the detection accuracy of the present configuration or prove that a particular image anomaly results from emitter clogging.

Because independent measurements of soil moisture, emitter discharge and operating pressure are not included, the study cannot confirm the physical cause of an observed anomaly, quantify water losses or estimate sensitivity and specificity against a verified reference.

Moreover, one principal plot per irrigation configuration means that observed differences may also reflect plot-specific soil, crop and microclimatic conditions. Conclusions should therefore be limited to the spatial and temporal patterns observed in the UAV data and their potential usefulness for prioritizing areas for subsequent inspection.

CONCLUSIONS

UAV-based thermal and multispectral imagery offers a potential non-invasive approach for identifying spatial anomalies associated with irrigation-related water deficits in surface and subsurface drip-irrigated potato. Combining thermal patterns with vegetation indices may help prioritize areas for further inspection. However, airborne imagery alone cannot confirm emitter clogging or determine its cause. The proposed approach should therefore be evaluated as a screening method for irrigation monitoring, with diagnostic accuracy established through future field validation.

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