UNMANNED AERIAL SYSTEMS FOR IMPROVING AGRICULTURE PRODUCTIVITY: CASE STUDY OF COFFEE PLANTATION MAPPING AND MONITORING IN VIETNAM

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ABSTRACT: Unmanned Aerial Systems (UAS) have become increasingly popular in recent years for agricultural applications in support of effective farm management and improved agricultural productivity. This paper aims at demonstrating the use of UAS for detail mapping and monitoring of plant health in Vietnam's coffee plantations in Lam Dong province, Vietnam. With low-attitude and flexible flight operations, a WingtraOne VTOL UAV equipped with a RGB camera and a MicaSense multispectral sensor was used to collect high spatial resolution and quality images under varying terrain and climate conditions in four flight missions during the 2020-2021 coffee season. Using Pix4Dmapper or Agisoft Metashape photogrammetric processing, high spatial and temporal resolution UAV-image products, including RGB and multispectral orthomosaics, DSMs, point clouds and various vegetation index (VI) maps, were generated for accurate smallholder farm mapping, species differentiation, tree recognition and counting and crop health monitoring. The paper also discusses the cost and technical benefits of the conducted UAV mapping as compared to conventional coffee farm monitoring methods.

1. INTRODUCTION

Precision agriculture (PA) is emerging in mainstream coffee farming to support effective farm management, enhance farmers' control and localized applications with minimization of resource usage, which requires effective monitoring technologies throughout the whole production process. Remote sensing (satellite or aerial photography) have long been applied for crop mapping and monitoring in large scale due to its spatial and temporal coverage. As one of the fastest developing technologies, UAVs have emerged in recent years as cost-effective platforms, rapidly replacing conventional aerial photography in land mapping with ultra-high spatial resolution aerial images of the earth's surface. UAVs of helicopter or fixed wing systems provide various options for versatile and effective image data acquisition and with recent development of Vertical-Take-Off-and-Landing (VTOL) models, UAVs significantly improved its operational capability in large scale surveys as well as in complex terrain conditions (Wingtra, 2021). And with low-attitude and flexible flight operations, UAVs can proactively acquire quality images at centimeter-level resolution in the regions with periodical adverse weather conditions and persistent cloud cover, which often hinders optical remote sensing systems. Based on particular project requirements, UAVs can be equipped with a range of image data sensors (e.g., RGB, multispectral or thermal cameras). The most established application based on UAV-acquired image data is to map land cover and to assess the health of crop vegetation. The maps of vegetation indices (e.g., near-infrared or red-edge based) derived from UAV multispectral images of a certain area enable the analysis of the intensity of solar radiation absorption in different wavelengths and therefore the condition of the monitored plants (Bhagat *et al.*, 2020, Lum *et al.*, 2016). Furthermore, the centimeter-level of accuracy of UAV mapping makes it possible to monitor the condition of individual plants and precisely identify issues within a certain farm plot for focused farming with precise applications of fertilizers, pesticides or herbicides. Altogether, mapping and imaging capabilities of UAV platforms with a range of sensors can be used throughout the whole production process with repeated imaging of critical crop growth stages can be obtained and analyzed in order to monitor crop dynamics and to plan production better and therefore improve productivity (Sylvester, 2016, de Castro, *et al.*, 2021).

This paper presents an experimental work on using UAVs for RGB and multispectral mapping and monitoring of smallholder coffee farms in Lam Dong province, Vietnam. The intent is to demonstrate a streamlined procedure for cost-effective UAV RGB and multispectral image data acquisition and processing applicable for hilly agriculture monitoring and potential uses of geospatial analysis products in accurate coffee farm mapping and plant health monitoring over one crop-season, which prove for the technical benefits of UAV mapping for recommended application in other coffee plantations areas.

2. STUDY AREA

Located in Lam Dong province, the study area (Figure 1) features hilly terrain with average elevation (above mean sea level) ranging from 1,000m (Di Linh highlands) to 1,500m (Da Lat city) and 1,600m (Lac Duong district), with the average slope ranging from 5-15^0 in Di Linh highlands to 10-30^0 in Da Lat and Lac Duong sub-areas and reaching 30-40^0 on some high-hills. With varying elevation, the area has favorable climate conditions for Arabica (in Lac Duong, Da Lat city) and Robusta (Bao Loc, Di Linh, Lam Ha districts) coffee plantations - average rainfall around 1,400-2,200 mm/year, short three-month dry season and mean annual temperature of 15-20^{0}C. High rainfall combined with abundance of surface and ground water resources provide sufficient watering conditions for coffee plantation in the study area, even during the dry season. The area is predominantly covered by fertile brown or red-yellow basaltic soils with some patches of faded gray soils. With favorable soil and climate conditions, the area is intensively cultivated with varieties of Robusta and Arabica coffee in smallholder farms of 0.4 – 3 ha in size. With the increase in global market requirements on sustainable coffee certification, farmers are encouraged to improve their compliance with environmental sustainability standards. Based on conventional farm inspection and monitoring, certification auditors highlighted problems such as nutrient deficiency, low quality seedlings, weed infestations, water stress and pest or disease attacks within the study area calling for better farm monitoring and timely advice on improved practices, such as necessary pest and disease controls as well as nutrient application.

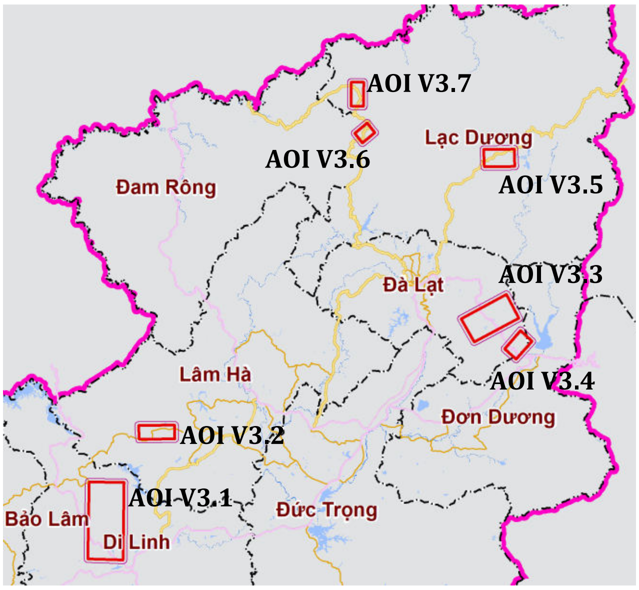

Figure 1. Study area map of seven AOIs with coffee plantations in Lam Dong province

Table 1. Coffee plantations mapped by UAV aerial photography in seven AOIs in Lam Dong province

Locations (AOI)	Address	Mean Elevation (m)	Slope range (^{0})	Coffee species	RGB mapping (ha)	Multi-mapping (ha)	No of coffee farms
AOI V3.1	Tab Chau & Tan Thuong, Di Linh	1000	5 – 10^0	Robusta	5,750	840	777
AOI V3.2	Tan Thanh, Lam Ha	1000	5 - 15^0	Robusta	1,215	270	162
AOI V3.3	Xuan Truong, Da Lat	1500	10 - 30^0	Arabica	3,070	520	363
AOI V3.4	Tram Hanh, Da Lat	1500	10 - 30^0	Arabica	995	275	94
AOI V3.5	Da Nhim, Lac Duong	1600	10 - 30^0	Arabica	1,315	215	125
AOI V3.6	Lan Tranh, Lac Duong	1600	10 - 30^0	Arabica	795	140	48
AOI V3.7	Dung K'no, Lac Duong	1600	10 - 40^0	Arabica	890	150	73

The experimental UAV mapping was conducted at seven AOIs (Area of Interest) of intensive Robusta and Arabica coffee plantations in Lam Dong province with a total area of 14,000ha (Figure 1 and Table 1).

3. UAS AND AERIAL SURVEY METHODS

3.1 Unmanned Aerial System (UAS)

Figure 2. The VTOL UAV WingtraOne

A VTOL UAV WingtaOne (Wingtra AG., Switzerland) shown in Figure 2 was selected to acquire ultra-high-resolution imagery for its efficient fix-wing flight, endurance, high performance and easy operation. With a pair of Li-ion 99Wh batteries and smart battery technology, WingtraOne can fly at 16 m/s for up to 59 minutes per flight for large coverage and with wingspan of 125cm, it can operate stable under sustained wind up to 12m/s. WingtraOne has a tail-sitter requiring minimum a 2 x 2m space for vertical take-off and landing (with auto-landing accuracy of less 2 m). With empty weight of 3.7kg, WingtraOne can carry swappable camera and propeller payloads up to 0.8kg. With redundant onboard GPS (and PPK capability for RGB mode), IMU and magnetometer sensors, WingtraOne comes with a tablet featuring WingtraPilot - the built-in app for easily managing data acquisition with highly-accurate geotags of flight images while controlling navigation, attitude, and communications in flight. The selected WingtraOne UAV proved to be very effective in conducting aerial photography in this study in both dry and rainy seasons covering large area (of 14,000ha) with complex hilly terrains.

A full-frame 42 MP Sony RX1R II camera and a MicaSense RedEdge-MX were selected and mounted alternatively on WingtraOne UAV (Figure 3) to obtain the imagery for RGB and multispectral mapping respectively. The high-end compact Sony RX1RII camera weighted 575g captures 42 megapixel sharp and undistorted nadir RGB images at minimal trigger time of 0.6s, resulting in a ground sample distance (GSD) of down to 0.7cm/pixel. And with 35mm focal length and horizontal FOV of 54.3 degree, Sony RX1RII camera offers high-speed data collections (covering up to 210ha in one flight at 120m flight altitude with 1.5cm/pixel GSD) at high horizontal accuracy (down to 1cm) with PPK GNSS receiver support.

Figure 3. RGB SonyRX1R II camera and MicaSense RedEdge–MX multispectral sensor

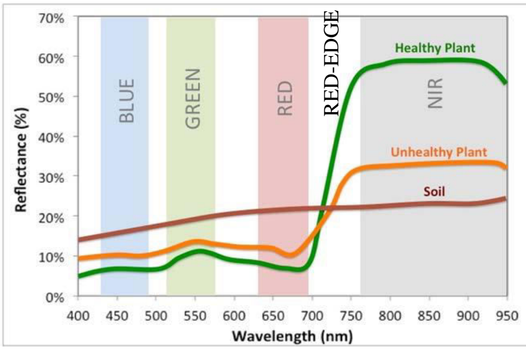

Figure 4. Sensor wavelength regions in UAV RGB and multispectral mapping of coffee farms

The MicaSense RedEdge-MX full-spectrum multispectral sensor (MicaSense Inc., 2021) weighted 325g acquires 1.23 MP images in five different spectral bands (blue, green, red, red edge and near infrared – Figure 4) with 12-bit (RAW format) radiometric resolution, allow for computation of RGB, NDVI, and advanced vegetation index layers in a single flight. With focal length of 5.5mm and horizontal FOV of 47.2 degree, RedEdge-MX can cover up to 150ha in one flight at 120m flight altitude (or 8cm/pixel GSD). Equipped with new DLS 2 light sensor for balanced image exposures in different bands and with embedded GPS, RedEdge-MX can reach maximal horizontal accuracy of 8cm. A Calibrated Reflectance Panel (CRP) comes with RedEdge-MX providing an accurate representation of light conditions during every flight, which allow for accurate compensation for changing light conditions during long UAV surveys.

3.2 RGB and Multispectral Image Acquisition

As the main objective of the UAV-based aerial photography (RGB or multispectral mapping) was to obtain imaging information on smallholder coffee farms for monitoring crop health over one full-crop cycle, the coffee phenological characteristics with weather conditions in Lam Dong province were considered in timing of flight missions. As a result, 4 UAV flight missions were selected for July, September, December 2020 and March 2021 covering critical stages of vegetative growth, grain expansion, grain maturation, harvesting and dormancy in the 2020-2021 coffee season (due to certain circumstances, the study could not start in March 2020 as planned). In order to find cost-effective and practical solutions for smallholder coffee farm mapping, a combination of UAV RGB and multispectral mapping were experimented in the study area. For that, a total of 14,000 ha in 7 AOIs was defined for UAV RGB mapping conducted in July 2020 for detailed farm mapping while 10 focused sub-areas within each of 7 AOIs were selected for UAV multispectral mapping in 4 missions for plant health monitoring. Considering the coffee plant geometry with leave size of 15-20cm and a crown size of 1-3m, a desired GSD of 10cm was selected for both RGB and multispectral mapping. For the defined mapping areas (Table 1) and using WingtraPlot, the flight plans were designed in each of 7 AOIs for 50-min flights and 70x70% overlap in RGB mapping and 75x75% overlap in multispectral mapping as shown in Figure 5.

Based on the designed flight plans, the UAV aerial mapping surveys were conducted in 4 flight missions using the standardized, quality-assured and well-tested methodology (Figure 6), including following data acquisition steps:

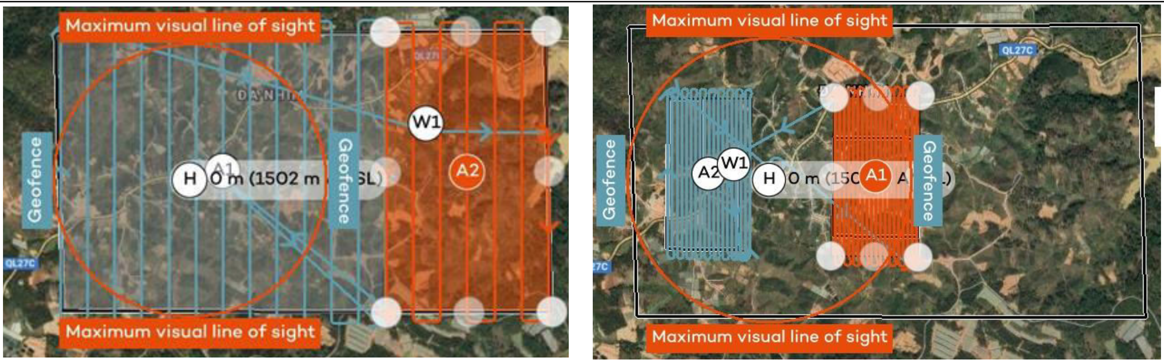

Figure 5. Flight plans using WingtraOne for RGB mapping (1,315ha, 2 flights at 745m altitude) and multispectral mapping (125ha, 2 flights at 147m altitude) in AOI V3.5 Da Nhim

- **Preparation:** UAV flight permission application, on-field equipment checking and surveying for take-off / landing locations.
- **Mission planning:** verifying planned flight parameters for each AOI with WingtraPilot (for both RGB and Multispectral cameras).
- **GCPs planning and collection:** A total of 78 GCPs were designed in seven AOIs with complex terrains, where accurate coordinates (÷3-5cm) were obtained using RTK GPS (Trimble R2) and photogrammetric targets (white painted cross ground markers of 1m long and 0.1m width) were established for subsequent photogrammetric processing.
- **Using the Base GNSS** (optional): Start the base station for RGB mapping to take advantages of built-in PPK technology for high mapping accuracy.
- **Flight, data loading and checking:** Check the environment conditions (weather, wind, rain) and operate the UAV flights. In case of multispectral mapping, capture an image of the CRP 2 before and after each flight to provide an accurate representation of light conditions for image calibration. After each flight, acquired images and GNSS data were loaded and checked for quality of photos, especially on illumination, haze or cloud cover (for re-fly if needed).

In total, 50 RGB mapping flights covering 14,000ha in July 2020 and 30 multispectral mapping flights for each of four flight missions covering 2,510ha in 7 AOIs were conducted, producing a large volume of high-quality in-flight images for routine processing and geospatial analysis.

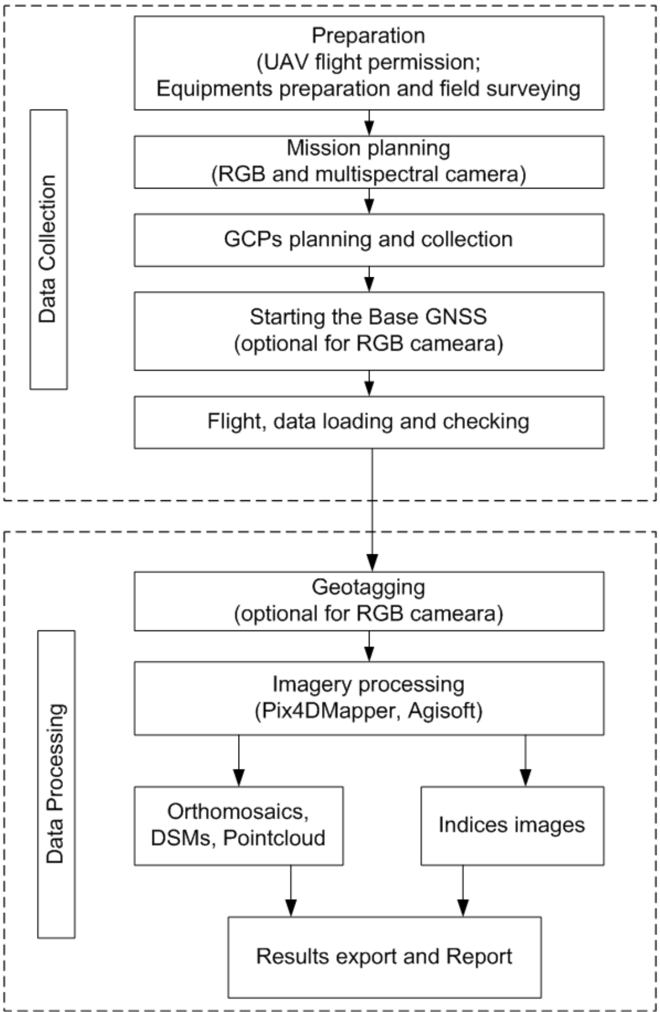

Figure 6. General methodology of UAV image data acquisition and processing for coffee farm mapping

3.3 Image Data Processing and Index Generation

With the sets of captured images grouped for each flight and by AOI, image data processing was conducted in following four steps:

a) **Geotagging.** After each flight the captured individual images must be geotagged - using the WingtraHub software to geotag the RGB photos orientation of photos).
b) **Photogrammetric processing:** Geotagged images for each AOI were inputted into the Pix4Dmapper for

processing routines, including with the GNSS base station data (to provide accurate exterior preprocessing/image alignment, tie point thickening, georeferencing with GCPs and then, creating dense point cloud, 3D textured mesh and mosaicking. For AOI V3.1 with large area of 5,750ha, Agisoft Metashape was used to process large volume of captured RGB photos. For RedEdge-MX captured data, radiometric calibration of ortho-mosaicked bands using the Radiometric Calibration Model in MicaSense Atlas software was additionally processed for subsequent change analysis. The derived outputs included: 7 sets of point clouds in LAS format (Figure 7), RGB orthomosaics, DSMs and DTMs (GeoTIFF format) for whole 7 AOIs dated July 2020; 28 sets of multispectral 5-band orthomosaics (calibrated reflectance) for mapped sub-areas of 7 AOIs in GeoTIFF format with 10cm pixel resolution and in WGS84/UTM zone 48N coordinate system.

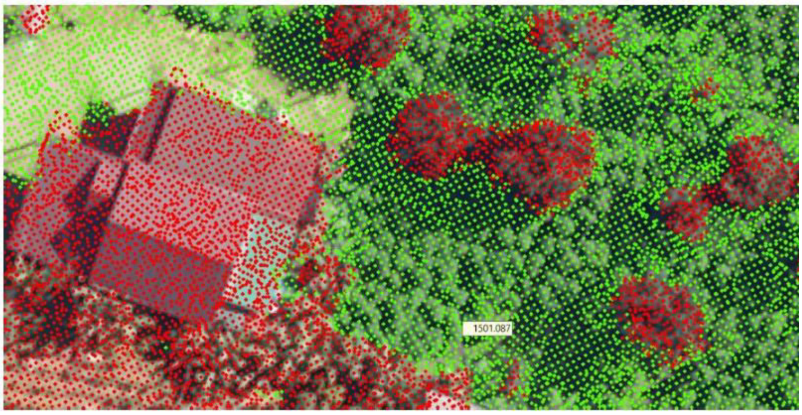

Figure 7. Generated and classified dense point clouds for canopy height estimation and DTM generation.

c) **Index generation.** Applying formulas in Table 2 for calibrated orthomosaic bands, vegetation index maps were generated in Pix4Dmapper or ArcGIS, including ExG and VARI for RGB mapping areas and NDVI, NDRE, LCI for multispectral mapping areas.

Table 2. The formula of indices imagery

Vegetation Index Maps	Formula
ExG – Excess Green Index	(2*GREEN – RED – BLUE) / (2*GREEN + RED + BLUE)
VARI - Visible Atmospherically Resistant Index	(GREEN − RED) / (GREEN + RED − BLUE)
LCI - Leaf Chlorophyll Index	(NIR − REDEDGE) / (NIR + RED)
NDRE - Normalized Difference Red Edge	(NIR − REDEDGE) / (NIR + REDEDGE)
NDVI - Normalized Difference Vegetation Index	(NIR − RED) / (NIR + RED)

d) **Quality assurance and image products finalization.** As image quality and mapping accuracy are very important for monitoring small plant-level changes, the same GCPs were used for 4 flight missions. Image quality of the resulted orthomosaics of 10cm resolution was reviewed in terms of illumination and cloud cover for re-flight and re-processing - around 10 RGB re-flights conducted for meeting desiredc quality. In addition, a total of 14 independent checkpoints (ICP) were selected across seven AOIs and measured independently with RTK GPS. The computed RMSE of 9cm horizontally and about 23cm in height showed a good accuracy for further interpretation and analysis, e.g., for creating coffee farm maps of at least 10cm resolution.

4. RESULTS AND DISCUSSIONS

The processed image products and ground truthing data were used in an integrated geospatial analysis for coffee farms mapping and monitoring in 7 AOIs over the 2020-2021 coffee season (see Tran Hung *et al.,* 2021 for more details on the analytical process and techniques applied). Some results demonstrating the signification of the use of UAVs for smallholder coffee farm mapping and monitoring as follows:

4.1 Coffee Farm Mapping and Farm Inventory

With 10cm-resolution RGB ortho-images and ExG maps acquired in July 2020, 1,642 smallholder coffee farms in seven AOIs were accurately mapped and inventoried as illustrated in Figure 8, including:
(1) coffee farm boundaries delineation with ArcGIS and verified by farm visits with GPS and/or authenticated by farm owners where productive areas (e.g., mature coffee plants) are differentiated from unproductive parts (e.g., young / re-planted coffee plants or ponds, houses, other plants, idle land) within each coffee farm – for accurate production estimation.

(2) mapping of abutting land uses and forest area encroachment – for compliance checking and certification.
(3) differentiation of intra-plot vegetation and non-vegetation portion for each coffee farm by ExG/NDVI thresholding and calculation of vegetation fraction (VF) in ArcGIS and (4) weed mapping and shade tree mapping with eCognition segmentation and point-cloud classification of canopy heights – for irrigation management and yield-loss factor estimation.
(5) coffee tree recognition (crowns) and counting with eCognition template matching – for detailed production inventory and yield estimation.

Figure 8. UAV mapped smallholder coffee farm boundaries with intra-plot sections (left); differentiation of exposed baresoil, weeds (upper right), shade trees and coffee plants; and mapped individual tree crowns (lower right)

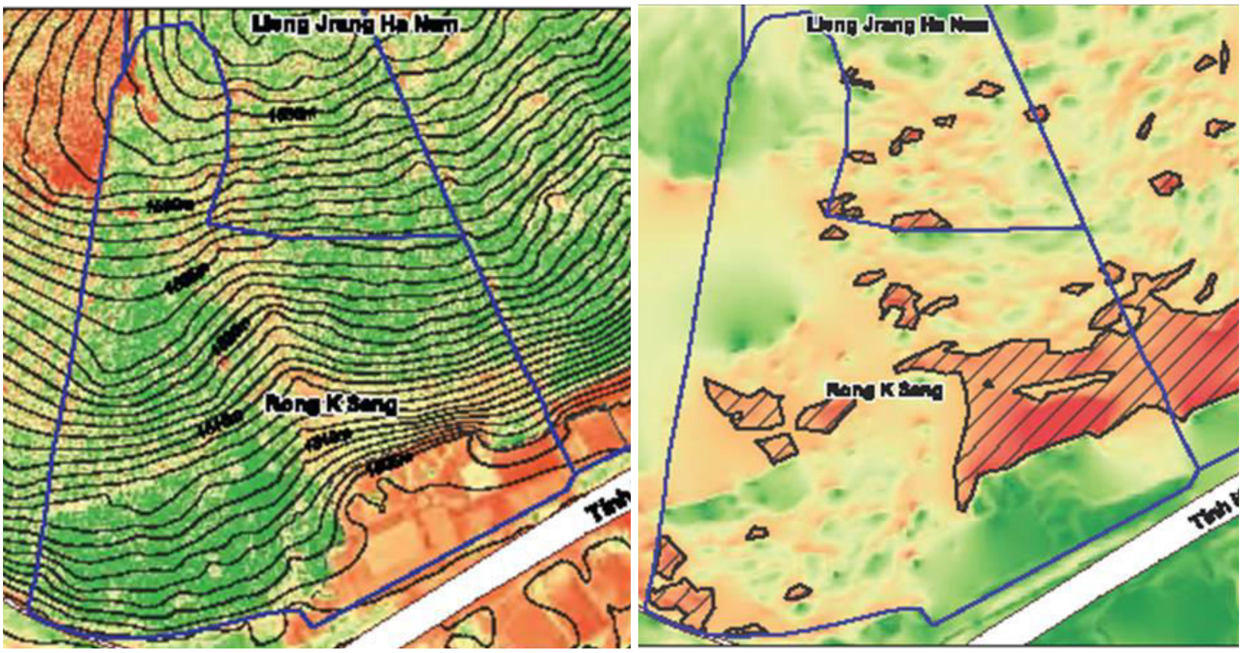

Figure 9. NDVI map for a coffee farm in AOI V3.7 in March 2021 (left); and UAV-based erosion risk map (right)

4.2 Terrain Modeling for Slope Management

Using the 10cm-resolution DTMs products, average slope maps were generated for all 1,642 smallholder coffee farms in 7 AOIs, based on which erosion risks were analyzed in ArcGIS combining high slope gradient with mapped vegetation cover/bare soil exposure as illustrated in Figure 9.

4.3 RGB versus Multispectral Vegetation Indices

For 558 coffee farms in UAV multispectral mapping areas in 7 AOIs, all 5 VIs listed in Table 2 were generated and significant high spatial correlations (sampled for mature coffee farms) of 0.83 ($p<0.01$) found between VARI and NDVI indicating for potential use of VARI as NDVI alternative for coffee farm mapping/ ranking as illustrated in Figure 10.

Figure 10. VARI score map for coffee farm health ranking.

4.4 Coffee Plant Health Monitoring

Using selected VIs (NDVI, NDRE and VARI), smallholder coffee farms in the study area were mapped in terms of general farm health and monitored in terms of changing plant health/ nutrient states over crop cycle, including:

(1) **General farm health classification.** Based on NDRE or NDVI scores (mean index values and its intra-plot variability) for 558 coffee farms in UAV multispectral mapping areas in 7 AOIs and VARI scores (as NDVI alternative) for remaining of 1,084 coffee farms in RGB mapping sub-areas), coffee farms were ranked into 6 groups with different farm advice on plant health / nutrition states, namely: (1) farms uniformly with good health/nutrition, (2) farms with good health/nutrition but highly varied, (3) farms relatively uniform with average health/nutrition, (4) farms with average health/nutrition and highly varied, (5) farms relatively uniform with poor health/nutrition, and (6) farms with poor health/nutrition and highly varied (see Tran Hung *et al.,* 2021 for more details).

(2) **Nutrient deficiencies detection and monitoring.** Threshold values of farm-averaged NDRE scores in July 2020 were defined in ArcGIS (assisted by in-field leaf-chlorophyll measurement by SPAD meter and field inspections) for identifying coffee farms with severe nutrient deficiencies and/or with water stress as illustrated in Figure 11. Applying relevant pixel-value thresholds on NDRE score maps, nutrient deficiencies in different parts of a farm were highlighted. In addition, thresholds were then defined for September, December 2020 and March 2021 for monitoring nutrient deficiencies in 558 coffee farms with detailed/timely farm advice.

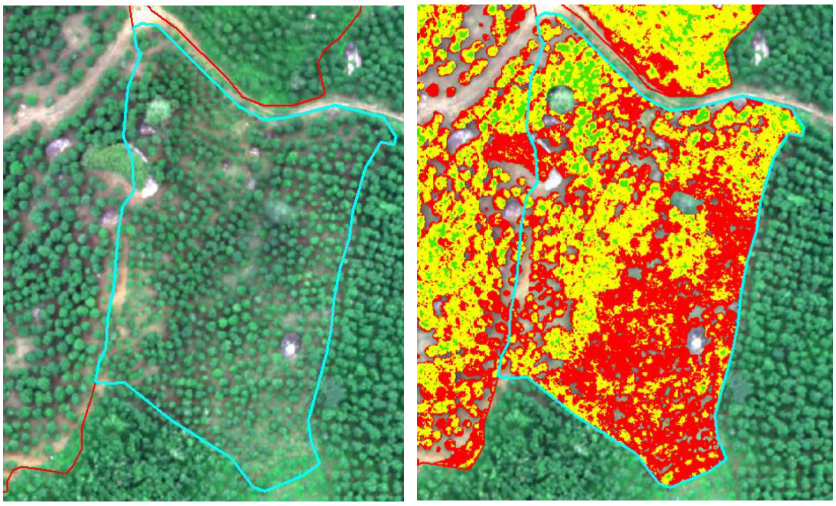

Figure 11. A coffee farm in AOI V3.7 with severed nutrient deficiencies mapped with NDRE scores in July 2020.

(3) **Early pests/diseases detection**. As pest and disease attacks are normally unevenly progressed over space, defining threshold values for intra-plot variations of NDRE score can help to detect early signs of pests or diseases infection. Farms with potential pest/disease attacks (detected in July 2020) were verified by in-field inspections and continuously monitored in subsequent stages (e.g., September, December 2020 and March 2021) based on change

thresholds of intra-plot NDRE variations - for its progression or regression (healing) of disease infection as illustrated in Figure 12.

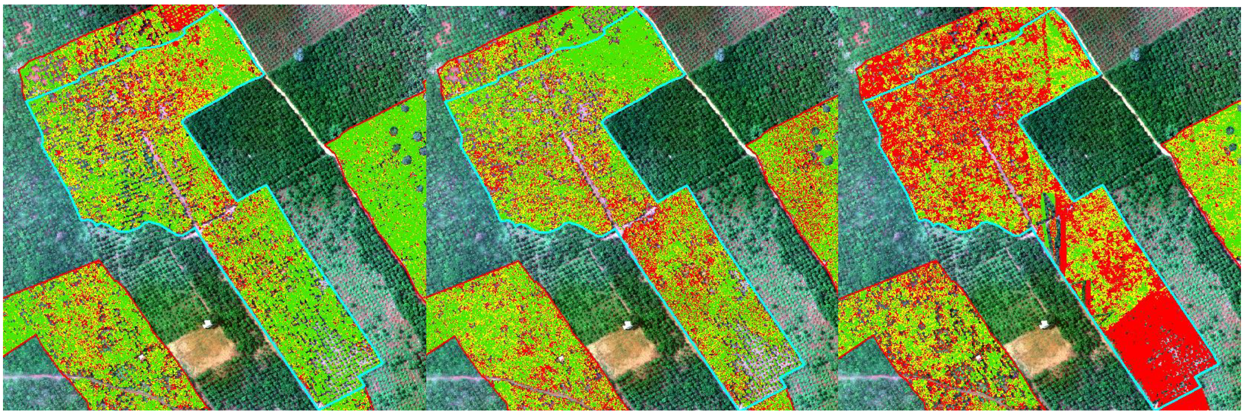

Figure 12. A coffee farm in AOI V3.1 with Nematodes and Moles infection detected by NDRE scores in July 2020 (left) and monitored for its progression by NDRE score in September (middle) and December 2020 (right)

4.5 Significance and Limitation of UAV-based Smallholder Coffee Farms Mapping

With traditional farming techniques, smallholder farm owners monitor their own farms by heart through day-to-day farm maintenance works. And only recently, under certain certification schemes (e.g., UTZ, 4C, CP or Rainforest), some farm mapping and monitoring efforts were conducted using conventional methods. In the area, farm boundary manual mapping with handheld GPS was a monumental effort the on complex terrains but with low accuracy. Farm information is reported by individual farmers are in-completed and unverified and no record for in-field monitoring of sampled farms or coffee plants in support of sustainable farm management. It worth noting that also no research report found on "use of UAVs in coffee farming application in Vietnam". With these current situations of coffee farming in Vietnam, the UAV surveys in this experimental work with presented analytical results demonstrated significance of UAV technology for smallholder coffee farm mapping and monitoring, with significantly comparative technical benefits as follows:

- High speed data collection with industry-level VTOL WingtraOne UAV covering 14,000ha scattered in 7 AOIs with complex terrain conditions in about 10 working days with RGB camera and 2,510ha scattered in 10 locations in a week with RedEdge-MX multispectral sensor;
- High quality of captured 10cm-resolution image data with support of advanced RTK technology provided for accurate mapping of smallholder coffee farms and sufficient details for plant level analysis;
- UAV surveys conducted 4 times (in July, September, December 2020 and March 2021) provide information for monitoring coffee plant growths, signs of plant stress and farming issues for timely intervention, thus help to improve crop productivity;
- With advanced geospatial analysis tools, UAV-captured image products combined with ground truthing data can be used for accurate coffee farm mapping (farm size) with detailed inventory of individual coffee plants (tree count/tree density, tree height, crown sizes) or for terrain modeling for slope management - as important information for farm inspections, certification/insurance and sustainable farm management and as essential parameters for yield estimation;
- As a measure of the leaf greenness and biomass, UAV-based NDVI can be used to monitor general crop health in coffee farms over time (four times in a crop cycle). In case of RGB mapping, VARI can be used as a low cost NDVI alternative in farm-level general crop health mapping, suggesting a need for a cost-effective combination of RGB and multispectral mapping for coffee farm monitoring;
- Red-edge based VIs proved to be a good plant health/nutrient indicator both at farm- and plant-level. NDRE scoring parameters (in terms of mean and intra-plot variability) help monitor nutrient levels of coffee farms and provide early indications of coffee plant health stress over various stages of a crop cycle in terms of: 1) nutrient deficiencies or water stress, 2) weed infestations and 3) pest or disease attacks for timely intervention and optimal fertilizing;
- The integration of UAV-analyzed information into a GIS farm database provide platform for integrating with ground truthing data and field measurements and reference data in order to improve analytical results and to generate individual farm cards with mapped information for timely farm advice.

On the other hand, this work revealed a number of limitations in UAV surveys and considerations for improvement as follows:

- weather factors (low cloud, haze, rains, gusted wind) preventing UAVs acquiring good quality images, which requires better local climate review and flexible mission planning to reduce re-flights;
- terrain factors (complex terrains with steep slopes) affecting the stability and duration of UAV operations – adding a multi-rotor UAV for complementation;
- information factors: for better phenotyping and detailed plant geometry consider 5cm resolution;
- cost factors (UAV surveys are still costly for smallholders): identify a cost-effective combination: (1) timing of first flight mission (RGB mapping) in February–March for best assessing farm conditions and unfertilized crop health in dormancy stage; (2) designs of low-cost RGB mapping wherever and whenever possible in place of multispectral mapping; or (2) reduce number of flight missions as July and September missions – while improve algorithms for best use of corresponded VIs;
- processing factors: improving processing algorithms and streamlining workflow for quality and timely analytical results;
- integration factors: maintaining GIS farm database with improved ground knowledge, reference and historical data for crop health incidences to support repeated UAV monitoring surveys.

5. CONCLUSION

Through the use of a VTOL WingtraOne UAV for smallholder coffee farms mapping in Lam Dong province, this paper demonstrated the significance of UAV technology in precision agriculture applications with high speed- and quality image data collection in complex terrains and climate conditions. The 10cm resolution RGB and multispectral image products captured by SONY RX1R II and MicaScence RedEdge-MX cameras in July, September, December 2020 and March 2021 provide detailed temporal information for monitoring coffee plant growths, signs of plant stress and related farming issues during the 2020-2021 coffee season for timely intervention, thus help to improve crop productivity. In addition to accurately map all 1,642 smallholder coffee farms with needed farm information, the use of NDRE helped to monitor nutrient levels of coffee farms and provide early indications of coffee plant health stress over various stages of a crop cycle in terms of: 1) nutrient deficiencies or water stress, 2) weed infestations and 3) pest or disease attacks for timely intervention and optimal fertilizing.

With rapid development of UAV and sensors technologies and processing algorithms (Radoglou-Grammatikis *et al.* 2020), further improvement in terms of image algorithms and localization of the technology procedures/workflow with local knowledge is needed in order develop a UAV-based practical and affordable crop monitoring solution in support of sustainable coffee farming in Vietnam.

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