Application of remote sensing by airborne systems to optimise agricultural production: the case of a rubber plantation

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Abstract: The main aim of this study is to determine the usefulness of airborne remote sensing in improving agricultural production, using rubber tree as a case study. Cameroon, plagued by natural disasters and outdated farming practices, is struggling to increase its agricultural output to meet the demands of industrialization. Given the multiple applications of remote sensing, the methodology consisted of acquiring images from two systems: airborne drones and satellites. Next, a fusion of these two types of images was performed, combining their characteristics. Thereafter, a series of treatments were applied to both types of images, separately and jointly; notably, the calculation of spectral indexes, colorimetric photo-interpretation, and the Hough transform associated with SLIC (Simple Linear Iterative Clustering). The main results are: assessment of the health and water status of the rubber plantation; identification of areas of water accumulation; and detection of weeds. All this is presented in the form of thematic maps, enabling targeted interventions and optimising the use of time, financial and human resources. All of this has a positive impact on production.

Keywords: Remote sensing, Airborne Systems, agriculture, rubber, agricultural optimization

1. Introduction

According to World Bank projections, the world's population will rise from 08 billion to over 09 billion by 2030, and to almost 10 billion by 2050. Such demographic expansion equally brings growing needs along; agriculture is thus becoming extremely important, being the main source of food production feeding the planet (Norasma et al., 2019), but also serving as a source of raw materials for solving other very varied needs involving industries (energy with biogas, housing, construction, mobility, and many others). Speaking of industry and raw materials, demand for the natural rubber derived from rubber tree cultivation and used as the basis for many manufactured products has increased (Dong et al., 2013). This surge in demand has led to a 25% global expansion of rubber tree plantations (FAO, 2010). This increase is not without consequences; the expansion of rubber cultivation is creating a number of problems between the production, management and conservation of forests (Guardiola-Claramonte et al., 2010; Li et al., 2008).

Towards its emergence by 2035, Cameroon has a strong ambition to achieve the status of a new industrialised country by 2030 (NDS30, 2020), increasing the contribution of the industrial sector to Cameroon's GDP to 24%. The industrialisation process is therefore seen as the foundation and cornerstone of Cameroon's development vision (MINEPAT, 2019). However, the effective development of the industrial sector is dependent on the agricultural sector; agriculture being a crucial development tool according to the World Bank in its 2008 World

Development Report, but plagued to non-modern methods and natural disasters such as the Yagoua flood (2024). With this in mind, in 2017, Cameroon adopted an industrialisation action compass, the Master Plan for Industrialisation (PDI), which highlights agro-industry as one of the central elements of the plan. Moreover, IRAD describes rubber as a crop with great industrial potential for Cameroon, with production expected to exceed 61,000 tonnes in 2021, of which almost 45% from HEVECAM, Cameroon's main rubber production company. Despite this substantial figure, it falls far short of expectations, as does world production, which will be nearly one million tonnes short of demand in 2023. In many regions, low yields combined with population growth have forced farmers to cultivate unsuitable land (either for technical or social reasons), resulting in deforestation and soil degradation in the short term (Saidou, 1992; NGO Global Witness, 2021) and, further afield, social concerns (eviction of local people); in the particular case of Cameroon, UNESCO World Heritage natural forests are being negatively impacted, according to RainForest Journalism, 2020. Consequently, one of the current challenges for a country that wants to emerge is to use innovative technologies applyable to agriculture (the driving force behind industrialisation) in order to satisfy the most varied current and future needs of the population without causing negative effects on the environment. Hence remote sensing by airborne systems, which offers many potential uses that have not yet been explored, let alone for a crop such as rubber. It would therefore be more than interesting to look at the advantages that this technology could offer in order to provide some answers to this problem: How can Cameroon's agricultural production be increased and its agriculture modernized?
The aim of this work is to determine the contribution of remote sensing by airborne systems in improving agricultural production of rubber trees.

Presentation of the stydy area

This section highlights the various physical characteristics of the study site, which is located in the Southern Cameroon region. The region will be presented in general and the site in question in particular.

Geographically speaking, the South region of Cameroon is located between 2°30‘North latitude and 11°45’ East longitude, representing one of the 10 country's regions. It is bordered to the north-west by the Littoral region, to the north by the Centre region and to the east by the East region. Its southern part is bordered by three countries: Equatorial Guinea, Gabon and the Republic of Congo; and its western flank is occupied by a coastline on the Gulf of Guinea (part of the Atlantic Ocean). With Ebolowa as its capital, the South region covers an area of almost 47,191 km² (INS,2023) divided into 04 departments and 29 subdivisions.

The southern region has a humid tropical climate, with abundant rainfall from April to November, divided into two seasons (the heavy season from March to June, and the light season from September to November). Depending on the location, the climate can be tropical monsoon, savannah or forest. The average temperature over the year is around 24°C (climateData.org) and rainfall averages 2890mm/year.

The southern Cameroon plateau dominates the relief of the region, with a minimum altitude of 0m and a maximum altitude of around 1000m. There are:

- A plateau in the east with a maximum altitude of 1000m;
- An Atlantic coastal plain 150km along the south of Kribi;
- A succession of convex hills whose altitude varies between 650 and 900 m;
- A plain in the east and north-east of the region.

As far as vegetation is concerned, the dense rainforest is the main forest formation, with variations such as the low-altitude coastal rainforest, the Congolese evergreen forest and the swamp forest.

The hydrographic network of the southern region is essentially made up of two basins. The Atlantic basin, with the So'o, Ntem and Lokoundje rivers; and the Congo basin, with the Dja, Lobé and Kienké rivers.

The soils in the area are mainly sandy-clay, with no coarse elements in the first few metres. The basaltic origin of the parent rock makes these soils rich in mineral elements. Yellow ferralitic soils on Gneiss cover most of the area, with red ferralitic soils and a sedimentary plain along the ocean coast.

The population of the South, which is predominantly young, is estimated at 749,552 (INS, 2023), with the region growing by 15.8% over 10 years. The main ethnic groups making up the population of the southern region are the Fang: Bulu, Bané, Ntumu, Mvae and Ewondo; the Sawa: Batanga, Badjeli, Mabéa, Bassa, Yassa, Ngoumba and Bagyéli (Pygmies). There have been a number of conflicts between the local populations and the industries located there, due to the expansion of these industries onto their land.

The region's cultural heritage and tourism assets include its forest reserves, such as the Dja reserve declared a UNESCO World Heritage Site, its UFAs (forest management units), the Campo-Ma'an national park; its waterfalls and cascades on its rivers, such as the Lobé; and its wide opening onto the Atlantic Ocean, making a total of more than a hundred tourist sites (INS, 2023). The main economic activity is agriculture, subdivided into subsistence farming and cash crops (rubber, palm, coffee, cocoa), forming the basis of the industries established in the region (Hévécam, SudCam, CDC, among others); to this can be added fishing and livestock farming, which are very popular activities. In addition, the region's agro-ecological potential opens the door to fruitful trade with neighbouring sister republics.

Our plantation is in the Nyé'té (Niété) district, one of the 09 districts of the Ocean department, whose capital is Kribi. Specifically, in V5 (Village5), it is located at a northern latitude of 2°43‘, an eastern longitude of 10°04’, an average altitude of 54 m above mean sea level and a distance of 45 km from Kribi. Covering an estimated area of eight hectares, the plantation belongs to a professional rubber producer (‘petit plantteur’) and has been in operation since 1999. It is easily accessible via tracks and improved roads. This is illustrated in Figure 1.

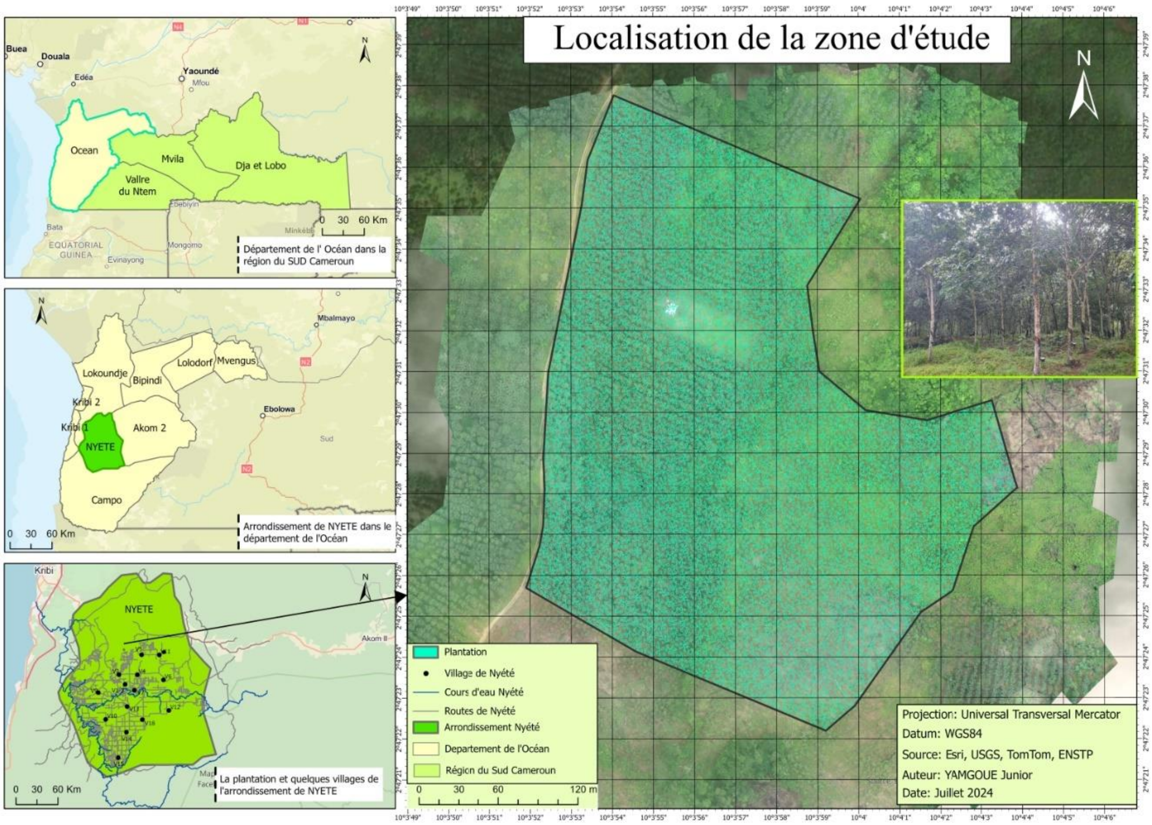

Figure 1 Localisation of the study area

2. Methodology

2.1 Datas

For this study, we mainly used UAV images and satellite images, combined with a question-and-answer session with the chief planter. The UAV images were acquired during a photogrammetric mission, and the satellite images were Sentinel 2.

2.2 Procedure

a- Ortho-Mosaic

The ortho-mosaic is obtained after processing and combining the images acquired during the photogrammetric mission. Aerial data will be processed using Pix4D Mapper software.

b- DTM and determination of water accumulation area

Digital terrain models (DTMs) are literally machine representations of the terrain under study. They represent the surface of the model as a regular grid of height values. A digital terrain model can be combined with an ortho photo to produce a 3D model of the area. Slope is one of the relief characteristics used as a basis for calculation. It is the ratio between the difference in altitude and the horizontal distance between two points on the relief. Determining an accumulation zone involves in this respective order:

- Filling in potential gaps
- Determining the slope
- Determining flow directions
- Determining the accumulation zones.

c- Image merging

In our case, fusion involves combining satellite and drone imagery, so that each can compensate for the limitations of the other. In particular, drone imagery balances the limitations of satellite imagery in terms of spatial and temporal resolution, while satellite imagery contributes in terms of spectral resolution and swath width.

The fusion operation is preceded by a series of steps:

- Stacking of satellite spectral bands using Envi software.

- Reprojection of coordinates to standardise the two systems; the satellite image being in geographic coordinates (WGS84: World Geodetic System 1984) and the drone image in projected plan coordinates (UTM: Universal Transverse Mercator).

- Resampling so that the two images (drone and satellite) have the same pixel size in the Erdas Imagine software. Since we are working on a small scale, we will carry out resampling involving aggregation by interpolation.

d- **Indexe Calculation**

Normalized Difference Vegetation Index

The NDVI is one of the most widely used vegetation indices for assessing the health and vigour of plant cover based on spectral images. This is due to its simplicity of calculation, its standardised nature and its reputation for being less sensitive to external factors such as the optical properties of the soil, the geometry of the illumination or atmospheric effects. To calculate the NDVI index, we use the reflectance of the red (R) and near infrared (PIR) channels measured in the visible band by sensors mounted on platforms such as drones. This index is given by the relationship:

$$NDVI = \frac{PIR - R}{PIR + R}$$

PIR represents reflectance in the near infrared range, while R represents reflectance in the red range. For a Sentinel-2 type image, these are band 8 and band 4 respectively.

Soil Adjusted Vegetation Index: SAVI

Although the NDVI index is particularly suitable for monitoring crop development because it measures the photosynthetically active biomass of plants, it is nevertheless imperfect because this index can be influenced by soil luminosity and atmospheric effects, which can distort the results. There are other indexes, such as SAVI, which mitigate these undesirable effects and offer a better assessment of vegetation.

$$SAVI = \frac{PIR - R}{PIR + R + 0{,}25} 1{,}25$$

Normalizes Difference Water Index

The NDWI (Normalized Difference Water Index) is expressed by the relation (McFeeters, 1996):

$$NDWI = (G - PIR) / (G + PIR)$$

PIR represents reflectance in the near infrared range, while G represents reflectance in the green range. For a Sentinel-2 type image, these are band 8 and band 3 respectively.

This index is designed to:

- Maximise the reflectance of water using green wavelengths;
- Minimise the low near-infrared reflectance due to the characteristics of water;
- Take advantage of the high NIR reflectance of vegetation and soil characteristics

e- Band composition and photo-interpretation

The aim is to create compositions of bands, interchanging these bands in the three display channels in order to obtain coloured compositions. These will serve as a basis for colorimetric photo-interpretation and visual analysis over this vast expanse of land.

f- Application of SLIC method and Hough transform

Dian and al (2017) developed an algorithm that takes drone imagery and applies the Hough transform and the SLIC (Simple Linear Iterative Clustering) method. This algorithm can be summarised in three steps: Background segmentation, field line detection and weed detection.

3. Results

Health status

After calculating the vegetation indexes, we obtain the vegetation state, which gives information about the state of health of the plantation. We can thus create three different classes: values less than or equal to 0.35 for plants in a poor state of health, values between 0.36 and 0.5 for moderately healthy plants and values greater than 0.5 for healthy plants. (Figure 2)

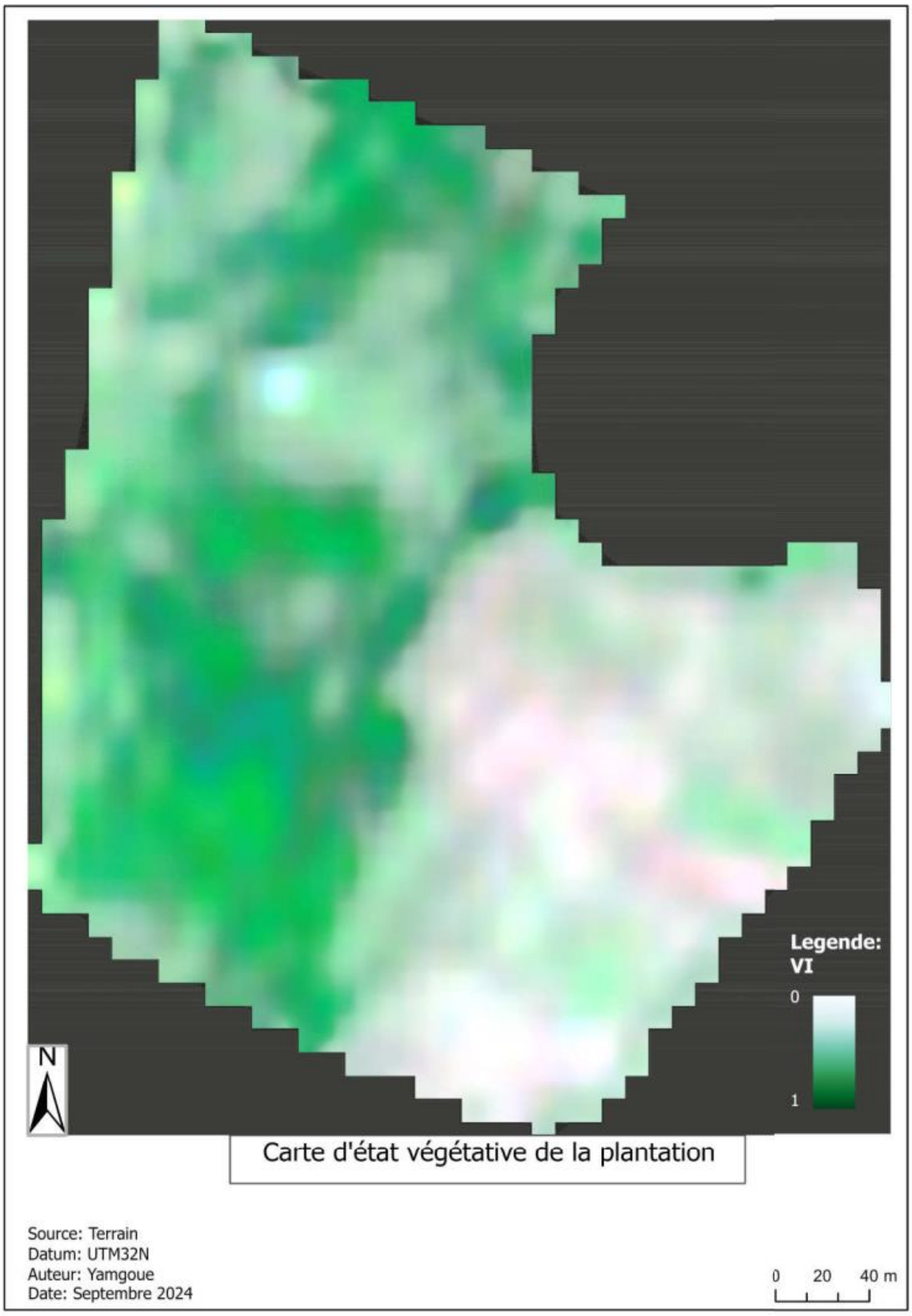

Figure 2. vegetative map

Water Status

We can create four different classes: values below or equal to -0.3 correspond to drought or non-water surfaces, values between -0.3 and 0.0 for low humidity, values between 0.0 and 0.2 for high humidity and values above 0.2 for water surfaces. The water status is shown on the map below.

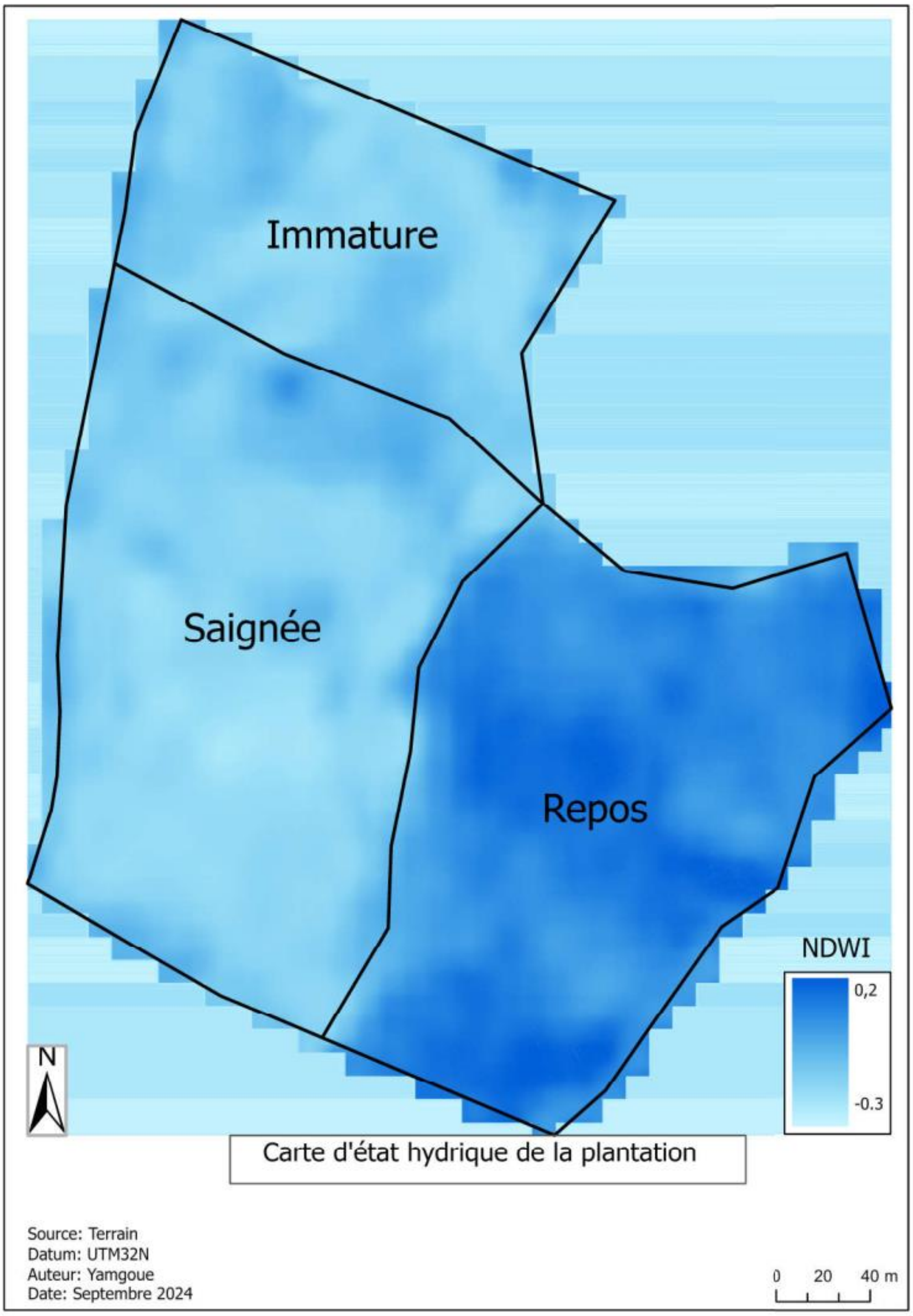

Figure 3. Hydric map

Weeds detection

The bright red pixels, that are different from the majority, highlight weeds. These are not bad in themselves (and sometimes have good virtues), but they are invasive for the rubber tree crop and therefore compete for nutrients for growth.

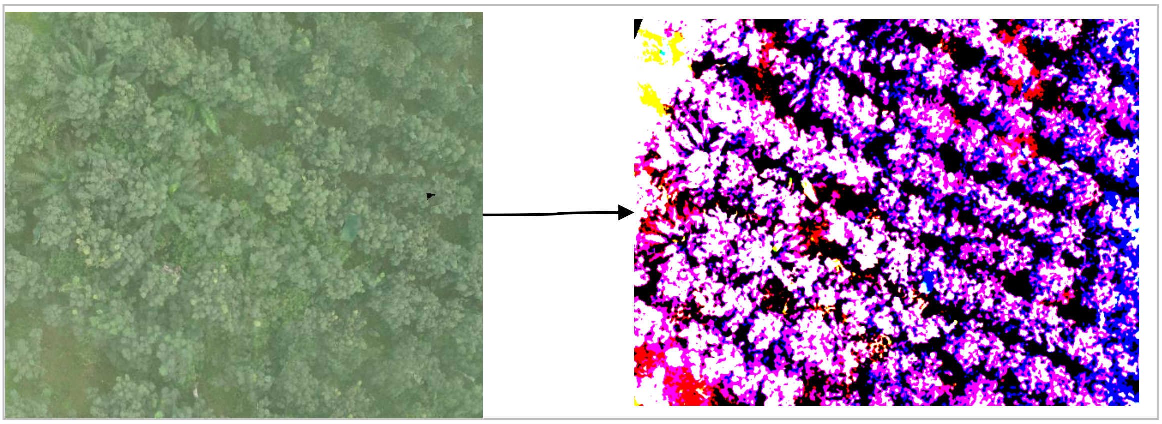

Figure 4. Weeds

The Hough transform combined with the SLIC method is effective in identifying weeds in immature plantations, but not very effective for plantations already in the tapping phase due to dense foliage. For the plantation in the tapping phase, colorimetric photo-interpretation is a good alternative to identify weeds.

Discussion

Remote sensing by airborne systems offers considerable advantages for agriculture. The combination of UAV and satellite images makes it possible to assess the state of health of a rubber plantation, but also to detect weeds and potential anomalies in the plantation. This will enable better management. The main results are presented in Table 1 below. This study could be improved by the use of sensors with more precise resolution, by integrating the agronomic characteristics of the rubber tree and by taking into account the very changeable surrounding climatic conditions.

Table 1. Main Results

Overview of results		
Elements of interpretation	Direct products	Concrete contributions
NDVI Map	Assessment of health status ;	Targeted and quantified intervention ;
SAVI Map	Nutritional requirements ;	Reduced costs ;
CDWI Map	Assessment of water status	Saved time
Ortho Photo + Coloured compositions	Remote detection of irregularities Thematic mapping	Preventive and targeted intervention Control of spaces and areas Effective monitoring of planting
Lignes de traits	Detection of weeds	Effective eradication
DTM	Accumulation zones	Better distribution of plants and landscaping (reduction of almost 10% in losses)

Conclusion

The aim of the study was to determine the contribution of airborne remote sensing to improving rubber production. The approach employed involved an initial site reconnaissance phase, enabling the precise localization and orientation of the study area. On which the two types of imagery were acquired. By merging these images, we were able to determine the state of health of our plantation using the NDVI, SAVI and NDWI indexes. This state of health gave us a better understanding of vegetation density and seedling vigour in the plantation. Using this information, we were able to identify the less vigorous areas (with nutrient and water deficiencies) and the more vigorous areas, which provides valuable information for taking appropriate measures, including better organisation of resources and targeted interventions to optimise growth and production. In the same vein, the SLIC method and the Hough transform were used to identify areas with weeds. Colorimetric photo-interpretation was used to detect irregularities and contribute to the thematic map. The use of remote sensing is therefore proving to be a significant contribution to improving agricultural crop production in general and rubber production in particular. Informed decisions can be made to optimise production, improve sustainability and contribute to socio-environmental security. There were, however, a number of limitations, including a lack of knowledge of the phrenological nature of the rubber tree; the use of sensors whose resolutions (mainly spectral and spatial) were not the best; and the fact that access to the plantation was conditional, which affected the in-situ confirmations in order to increase the accuracy of the results.

In the future, this work could be completed by a study on the integration of autonomous intervention systems using drones based on artificial intelligence, coupled with a specialised geographic information system highlighting variable rate treatments (VRT).

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The rubber planters in the area who provided access to their sites for this study.

What your study provides

This study provides:
An agricultural approach based on remote sensing, in a cameroonian context.

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