Spectral Reflectance-Based Estimation of Vegetation Biophysical Parameters Using Sentinel-2 images in Malegaon, Maharashtra, India (20.60°N, 74.52°E)

Firdaus Ara. J.[1*], Sayyad Shafiyoddin[2], Shoaib. M. Momin[3], R. N. Shaikh[4]

ABSTRACT

The spectral reflectance from vegetation canopies is a surrogate measure of vegetation biophysical parameters, and hence can be used to monitor the health and function of vegetation. This study explores how satellite images can be used to understand the health and condition of crops in the Malegaon region of Nashik district, Maharashtra, India. The main aim is to estimate important crop features — known as **biophysical parameters** — such as chlorophyll content, leaf area, canopy water content, fractional vegetation cover, fraction of absorbed photosynthetically active radiation, etc, by studying the way crops reflect sunlight, which is technically called **spectral reflectance**. We used data from the **Sentinel-2 satellite**, which captures high-resolution images in multiple bands of light, including both visible and invisible (infrared) ranges. The analysis was carried out using **SNAP software**, developed by the European Space Agency (ESA). To make the study more reliable, we also collected field data manually from selected crop fields, known as **ground truth data**.

The study was carried out in the winter season, November 2024, when three major crops commonly grown in the region — **Wheat (Triticum aestivum)**, **fodder (Sorghum bicolor)**, and **Guava (Psidium guajava L.)** were selected for analysis. These crops were studied during their active growth stages when chlorophyll levels are naturally high. The model used here is the PROSAIL model, which is among the best transfer models for computing biophysical parameters.

Our findings show that the chlorophyll levels estimated from satellite data closely match the values measured directly from the field. This proves that satellite-based remote sensing is a **practical, low-cost, and time-saving** way to monitor crop health, especially in regions where regular physical surveys are difficult.

This approach is highly beneficial for farmers, agricultural officers, and researchers. It allows for early detection of crop stress due to drought, pests, or poor soil, helping farmers take corrective action on time. Overall, the study promotes the use of **precision farming** in semi-arid areas like Malegaon and can contribute to **sustainable agricultural practices** in India.

[1] Research Scholar, Dept. of Physics, K.S.K. College, Beed, Maharashtra, India
[2] Professor, Dept. of Computer Science, Milliya Arts, Science and Management Science college, Beed, Maharashtra, India
[3] Research Scholar, Dept. of Physics, SNJB KKH Arts, SMGL Commerce, SPH Science College, Chandwad, Maharashtra, India
[4] Professor, Dept. of Physics, Milliya Arts, Science and Management Science college, Beed, Maharashtra, India

Keywords: Remote Sensing, Spectral Reflectance, Biophysical Parameters, Sentinel-2, SNAP Software, CWC, LAI, FVC, fapar, Chlorophyll, Crop Monitoring, Wheat, Precision Farming, Malegaon, Sustainable Agriculture

Introduction

In agriculture, knowing the health of crops at the right time is very important. Farmers often face challenges like drought, pests, diseases, and poor soil, which can affect crop yield. Traditionally, farmers would physically inspect their fields to understand crop conditions. However, this method is time-consuming, especially for large farms, and it may not always give early warning signs of crop stress.

In recent years, modern technologies have helped us monitor crops more effectively. One of the most useful tools is **remote sensing**, which means collecting information about the Earth's surface without touching it, mostly using satellite images. These images capture how sunlight is reflected from the ground, including crops. Plants reflect light differently based on their health, water content, and chlorophyll levels. This reflected light is called **spectral reflectance**, and it acts like a “fingerprint” for different types of crops and conditions.

Satellites such as **Sentinel-2**, launched by the European Space Agency, capture images in multiple **spectral bands**, including the visible (red, green, blue) and invisible parts of light (near-infrared and shortwave infrared). These bands are particularly helpful for studying vegetation because healthy plants reflect a lot of near-infrared light but absorb more red light due to chlorophyll activity. By analysing this reflected light, we can estimate the **biophysical parameters** of crops — such as chlorophyll content, leaf area index (LAI), canopy water content, fapar, etc.

In this research, we focused on using Sentinel-2 images to assess the health of three key crops — **Wheat (Triticum aestivum)**, **fodder (Sorghum bicolor)**, and **Guava (Psidium guajava L.)** — grown in **Malegaon**, a city in Nashik district, Maharashtra (20.60°N, 74.52°E). This region has a **semi-arid climate**, with hot summers, mild winters, and seasonal rainfall from June to September. The local soils include **black soil**, **brown soil**, and **medium soil**, which support a variety of crops.

To understand the actual crop condition on the ground, we collected **ground truth data** by visiting farms and recording GPS locations, crop photos, and leaf information. We then processed the satellite images using **SNAP software**, a free and powerful tool developed by the European Space Agency. With this, we calculated important biophysical parameters like **Cab, CWC, LAI, fapar, and FVC**. These parameters give us an easier way to indicate how green or stressed the crops are.

By combining satellite data with field data, we were able to estimate chlorophyll levels and monitor plant health. Our method helps detect early signs of stress in crops and gives useful information without the need for daily field visits. This is especially useful for **agriculture officers, researchers, and farmers**, who can take timely actions to improve crop yield, save water, and reduce the use of unnecessary fertilisers or pesticides.

This study also highlights the importance of using **low-cost and open-access satellite technology** for sustainable agriculture in rural and semi-arid regions like Malegaon. The techniques discussed here can be applied in other similar parts of India to improve farming decisions, reduce risks, and support **precision agriculture** for a better future.

STUDY AREA and CROP SELECTION

About the Study Area – Malegaon, Maharashtra

This research was carried out in **Malegaon**, a city located in the **Nashik district of Maharashtra**, India. It lies at about **20.60° North latitude and 74.52° East longitude**. Malegaon is a well-known agricultural area, where farming is a major source of livelihood for many families. The region experiences a **semi-arid climate**, which means it is mostly dry for large parts of the year but gets **good rainfall during the monsoon season** (from June to September). Because of this mix of dry and wet conditions, it becomes an interesting place to study the growth patterns of crops throughout the year.

The **soil types** found in Malegaon are **black soil (regur)**, **brown soil**, and **medium soil**, each of which supports different crops:

- **Black soil** is ideal for crops like fodder because it holds moisture well.
- **Brown soil** is more common in drier areas and is suitable for fruits and vegetables, and grains guava.
- **Medium soil** supports a variety of crops like wheat and bajra.

Due to these favourable conditions, **Malegaon farmers grow a wide range of crops**, including **cotton, maize, pomegranate, guava, onion, fodder, wheat, cabbage**, and many more. In this study, we focused on **three major crops** — **Wheat(Triticum aestivum)**, **fodder (Sorghum bicolour)**, and **Guava (Psidium guajava L.)** — because they are widely grown and have clear spectral reflectance characteristics that can be studied using satellite images.

Selected Crop Locations for the Study

To make our study accurate, we selected specific crop fields based on actual farm visits. For each crop, **exact GPS coordinates** (latitude and longitude) were noted down to match with satellite images later. This process helps to create a direct connection between what we see on the satellite image and what’s growing on the ground. The selected crop area is approximately 12 acres. Located in the southern region of Malegaon along Malegaon national highway number 3 bypass near Hotel Shalimar, with 3 major crops

Here are the specific crop areas:

● **Wheat fields** were selected in the area between **20.524110°N to 20.53177°N** latitude and **74.527930°E to 74.527627°E** longitude. (2 acres approx.)

● **Fodder fields** were selected between **20.524020°N to 20.522937°N** latitude and **74.527371°E to 74.526793°E** longitude. (5 acres approx.)

● **Guava fields** were selected in the region between **20.524110°N to 20.523177°N** latitude and **74.527930°E to 74.527627°E** longitude. (2 acres approx.)

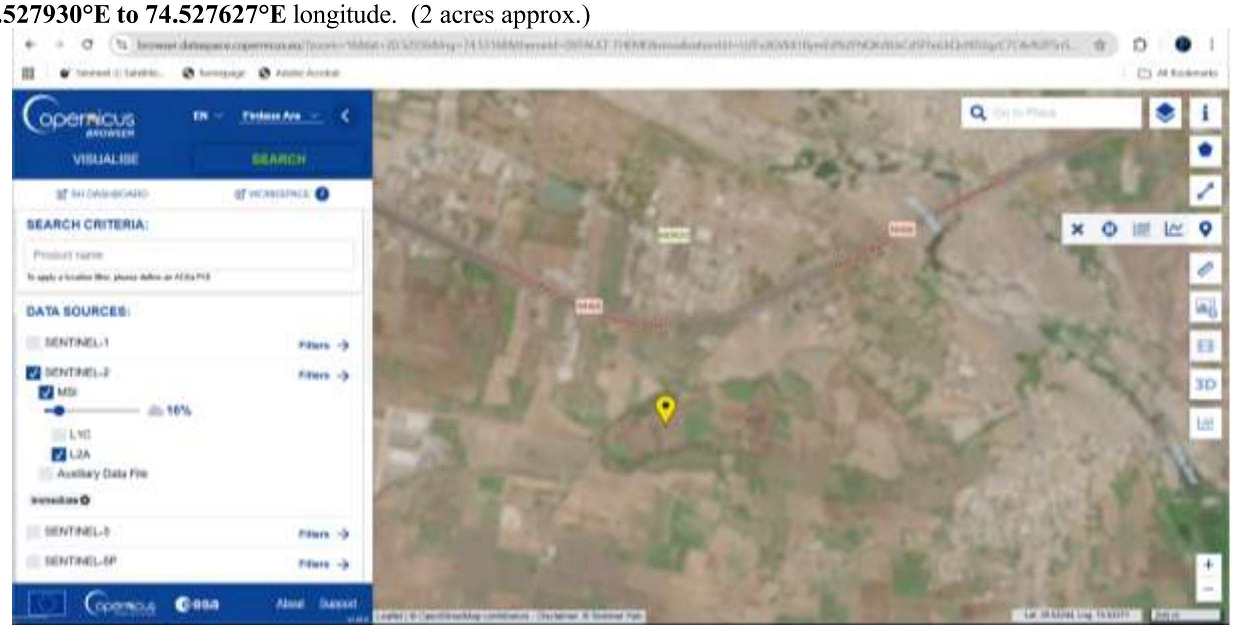


Figure: Area of study, Malegaon (subset Badi Bagh)

DATA COLLECTION

Ground Truth Data Collection (Field Survey Work)

Before starting the satellite analysis, we visited all selected farms in person. This step is called **ground truthing**, and it is very important in remote sensing. Without knowing what is really on the ground, satellite data alone may not give a clear picture.

During the field visits:

●**Photographs** of each crop were taken.

●The **GPS location** using a mobile phone or GPS device was recorded.

●Crop conditions like **leaf colour, leaf size, and plant health were noted down**.

We made sure to select **healthy, clearly visible, and undisturbed crops** to avoid any confusion later while matching with satellite data.
This ground data acted as a **reference** to validate or double-check the information we get from satellite images. If satellite values matched with field observations, then it indicates that the model selected here is working properly.

Satellite Data Collection – Sentinel-2 Images

After the field survey, **free Satellite images were downloaded** from the **Copernicus Open Access Hub**, which is maintained by the **European Space Agency (ESA)**. Here the **Sentinel-2 satellite images were seleted**, which is specially designed for vegetation and land monitoring. It captures **multispectral images**, in 13 bands ranging from wavelength 443nm to 2190nm, involving Near Infrared(NIR), Shortwave Infrared(SWIR) and Visible Regions. specially L1A,L2A,L1B and L2B were seleted by avoiding L1C product to collect the reflectance information from Bottom Of Atmosphere(BOA).
For this study, we selected the **image dated 24 November 2024**, because at this time of the year, crops in Malegaon are in the **early to mid-growth stage**. During this period:

●Leaves are fresh and green,

●Chlorophyll content is high,

●Plants are not fully mature but are actively growing.

This stage is perfect for studying **plant health using spectral reflectance**, especially for estimating chlorophyll content.

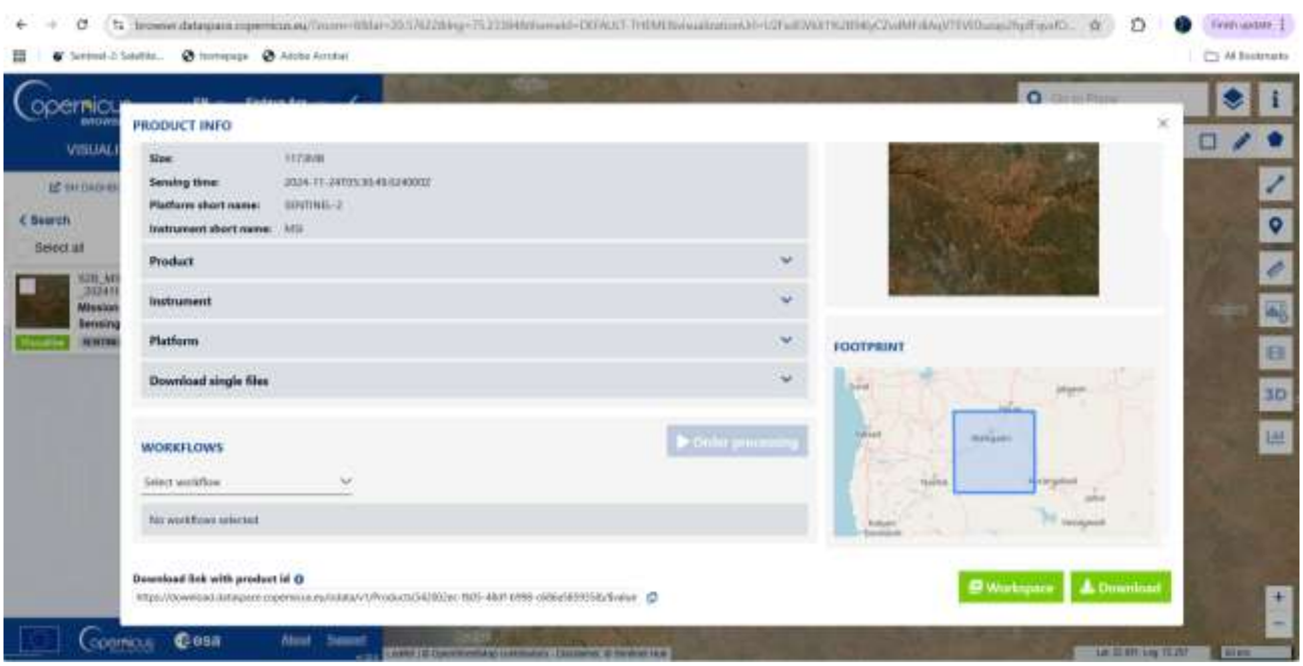


Figure: sentinel-2 data collection

Final Dataset

After completing these steps, we had:

●Ground truth data (from field survey)

●Satellite data (Sentinel-2, dated 24 November 2024)

●Image subsets (one for each crop)

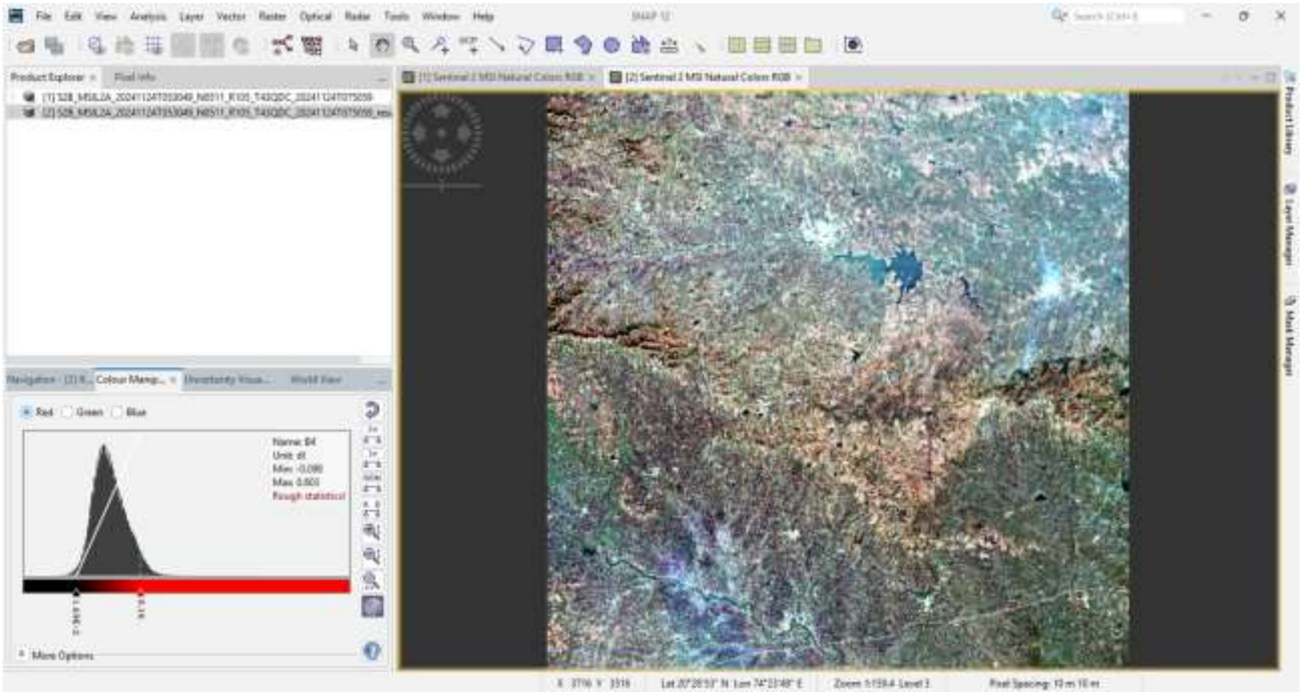


Figure: SNAP software data analysis

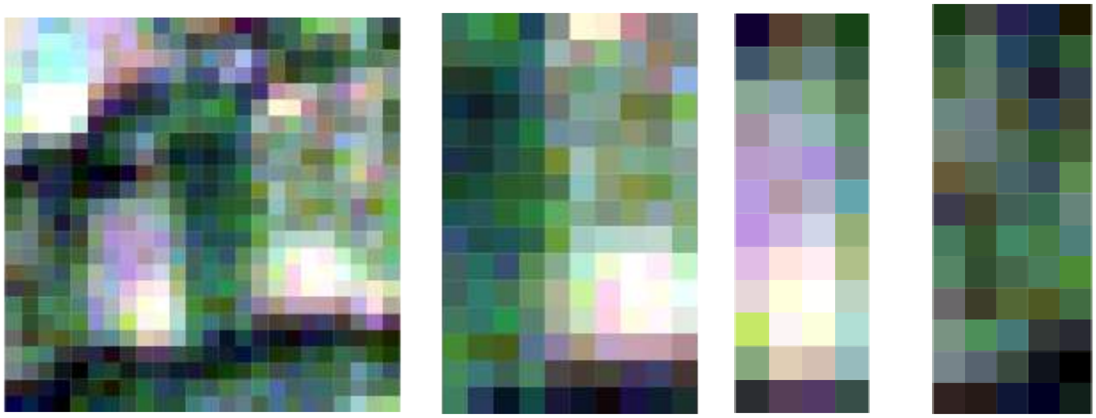
This **combined dataset** was used for all further analysis to estimate Biophysical parameters using the PROSAIL model. This method of combining ground and satellite data is **low-cost, non-invasive**, and very practical especially for regions like Malegaon, where access to expensive equipment is limited but the need for smart farming is high.

Materials And Methodology

This study was based on combining both field surveys and satellite image analysis to estimate important biophysical parameters of crops in Malegaon, with a special focus on understanding **chlorophyll content** and **plant health**. The overall method was designed to be simple, cost-effective, and usable with basic tools and free software. It can be divided as:

1. Software Data Analysis:

The downloaded Sentinel-2 images were then analysed in SNAP software, which is freely provided by the European Space Agency (ESA). SNAP (Sentinel Application Platform) is a powerful tool to process satellite images and extract useful information like vegetation indices, chlorophyll levels, Biophysical parameters and land cover. While downloading Sentinel-2 images from the Copernicus open access hub, L2A and L2B images are preferred as they contain the reflectance from BOA(Bottom Of Atmosphere), whereas L1C images are avoided because they contain reflectance from TOA(Top Of Atmosphere). This step is important because only surface reflectance gives true and usable data for estimating chlorophyll and other vegetation parameters. After that, the downloaded images of the area of interest(AOI) were opened in SNAP and subjected to necessary pre-processing, like resampling to make the same resolution for all the bands, atmospheric correction if required, and then making subsets for AOI. For this, we used the GPS locations collected during the field visit to create subsets from the full satellite image. A subset means we crop out or cut the exact area from the image where our crop of interest is located, so that the rest of the image (like roads, water, buildings, or other crops) does not interfere with the analysis. These subsets were created separately for Wheat, Guava, and Fodder using their recorded coordinates as shown in the figure.



(a) (b) (c) (d)

Fig. Subsets in SNAP (a) Total Crop Area (b) for Wheat (c) for Guava (d) for Fodder

After making proper subsets, the crop biophysical parameters are estimated using the sen2cor processor involving PROSAIL(PROspect+SAIL) model. The biophysical parameters estimated here are Leaf Area Index(LAI), Fractional Vegetation Cover(FVC), Canopy Water Content(CWC), Chlorophyll a/b concentration, and fraction of absorbed photosynthetically active radiation(fapar). Out of these, only the Chlorophyll ab concentration is compared manually with lab data in this research work. For estimating pixel-wise values at each latitude and longitude for the parameters, we can use either Python Pro. Programming or QGIS software. Here, we use **QGIS** software for estimating exact values for each data set. The chlorophyll concentration values estimated by PROSAIL model are actually the Leaf Chlorophyll Concentration(LCC). We can convert it to Canopy Chlorophyll Content(CCC) by simply multiplying by Leaf Area Index(LAI). In this research work, we incorporate only LCC at both satellite data and filed data.

Field Data Analysis:

The field samples acted as **ground truth data,** played a vital role in checking whether the satellite readings were correct. The collected ground truth data for the crops is then analysed in a laboratory to check the correctness of the results. Here, only chl. ab concentration is calculated by using a UV-Visible spectrophotometer using by below procedure.

Step 1: Sample Preparation: Collect fresh leaves and weigh approximately 1-2 grams of the leaf material. Rinse the leaves with distilled water to remove any contaminants.

Step 2: Extraction of Chlorophyll: Grind the weighed leaves using a mortar and pestle with 10-15 ml of 80% acetone. Transfer the mixture and filter it through a filter paper to collect the chlorophyll extract.

Step 3: Dilution: Measure the extract volume and dilute with 80% acetone if necessary, ensuring absorbance readings are in range.

Step 4: Spectrophotometric Measurement: Set the spectrophotometer to 663 nm for chlorophyll a and 645 nm for chlorophyll b. Calibrate using 80% acetone as a blank and measure the absorbance of the chlorophyll extract.

Step 5: Calculations Use the following formulas to calculate chlorophyll concentrations:

Chlorophyll a (mg/g) = [(12.7 x A663) - (2.69 x A645) x V] / [1000 x W]

Chlorophyll b (mg/g) = [(22.9 x A645) - (4.68 x A663) x V] / [1000 x W]

Chlorophyll ab (mg/g) = Chlorophyll a + Chlorophyll b

Where: • A663 = absorbance at 663 nm
• A645 = absorbance at 645 nm
• V = total volume of the extract (mL)
• W = weight of the leaf sample (g)

To complete the study, **satellite-derived values** (chlorophyll a and b) were compared with the **manually measured chlorophyll** data collected from the farms. This comparison helped us check the accuracy of the satellite-based results. In most cases, although satellite estimates were slightly lower, they followed the same pattern as the field measurements — confirming that this method is trustworthy and effective.

The figure below shows the overall steps in estimation of chlorophyll concentration by using UV-Visible spectrophotometer.

Fig. Estimation of Chlorophyll concentration Using spectrophotometer

Results And Analysis

After conducting the field visits and collecting crop samples from various agricultural plots in Malegaon, the satellite imagery from **Sentinel-2 (dated 24 Nov 2024)** was processed using **SNAP software**. We aimed to estimate the **chlorophyll content** from satellite reflectance data and compare it with the **manually measured field values**. This allowed us to assess the accuracy and reliability of satellite-based analysis for real-world crop monitoring.

Three important crops are mainly focused here from the Malegaon region — **Wheat(Triticum aestivum)**, **fodder (Sorghum bicolour)**, and **Guava (Psidium guajava L.)** — each sampled from specific geographic coordinates marked using GPS during the survey. The chlorophyll content from both sources (field and satellite) was recorded in **micrograms per square cm(μg/cm^2)**.

1. Wheat Crop Results – Analysis and Interpretation

The wheat fields were located between **20.524474°N latitude to 20.523199°N latitude** and **74.52889°E to 74.528073°E longitude**. These plots were mostly flat and well-irrigated, with wheat plants in their vegetative stage—characterised by tall green stalks and leaves with high chlorophyll content.

During the field visit, each sample was collected carefully at almost 5 different positions. The leaves appeared vibrant and uniformly green, which visually indicated healthy photosynthetic activity. These freshly collected samples are then carried out to the laboratory for further analysis. The observations were then matched against reflectance-derived chlorophyll values from the Sentinel-2 image after processing in SNAP. Also, other biophysical parameters like CWC, FVC, LAI, and fapar were estimated in SNAP.

Here is the comparative data of Chl a/b concentration for the wheat crop:

Sample ID	**Latitude**	**Longitude**	**Chlorophyll conc. from Satellite (μg/cm^2)**	**Chlorophyll conc. from Field (μg/cm^2)**
W1	74.52779	20.52405	44.1932	49.52478
W2	74.52797	20.52387	64.0924	65.1254
W3	74.52779	20.52387	31.2707	31.9752
W4	74.52797	20.52332	51.8939	59.7896
W5	74.52797	20.52323	58.1136	60.0012

As seen from the table, the chlorophyll levels estimated through satellite data **follow a similar trend** to field values. Although there is a slight underestimation, the consistency in values indicates a strong **positive correlation** between field and satellite data. This variation may be attributed to minor environmental factors such as soil background interference, cloud cover, or shadowing effects in satellite imagery.

Notably, Sample W2 shows the highest field-measured chlorophyll (65.1254 **μg/cm²** mg/g), and also the highest satellite-derived value (64.0924 **μg/cm²**). Likewise, Sample W3 shows the lowest values in both methods. This kind of matching pattern proves that remote sensing using **Sentinel-2 reflectance** is capable of identifying subtle variations in chlorophyll content, especially during the active growth phase of wheat.
Overall, the results confirm that **satellite-based chlorophyll monitoring is feasible and effective** for wheat, offering a non-invasive and scalable method to track crop health over time.

2. Guava Crop Results – Analysis and Interpretation
Guava, a prominent fruit crop in the Malegaon region, was the second crop selected for chlorophyll assessment. Unlike wheat and Fodder, Guava is a **woody perennial shrub or small tree** with a more **irregular canopy structure** and a mix of **young and mature leaves**. The orchards were located between **20.524110°N and 20.523177°N latitude**, and **74.527930°E to 74.527627°E longitude**, with trees planted in well-defined rows across gently sloped terrain.
During the field survey, individual leaves were selected from different levels of the canopy to represent an average reading. The leaves appeared dark green and leathery, which is typical for guava foliage during the early fruiting stage.
Field measurements of chlorophyll ab concentration using a spectrophotometer revealed moderate to high values of chlorophyll, which we expected to be reflected in the satellite data as well.
The corresponding subset of the **Sentinel-2 image (24 November 2024)** was processed using SNAP software, with chlorophyll-ab and other biophysical parameter values calculated from reflectance data using the PROSAIL model.
The comparative data of chlorophyll concentration are as follows:

Sample ID	Latitude	Longitude	Chlorophyll conc. from Satellite (μg/cm²)	Chlorophyll conc. from Field (μg/cm²)
G1	74.5277	20.52405	44.1932	49.0932
G2	74.5277	20.52387	29.2706	35.2546
G3	74.52779	20.52332	24.5485	30.1257
G4	74.52788	20.52332	23.722	30.1123
G5	74.52788	20.52323	25.1204	30.2549

From this table, we observe a **very clear relationship** between field and satellite values. The chlorophyll content gradually decreases from Sample G1 to G5 in both datasets. Sample G1, with the highest field value of 49.0932 **μg/cm²**, also showed the highest satellite-derived value of 44.1932 **μg/cm²**, while Sample G4 showed the lowest in both categories.
The slightly lower values from satellite estimation may be due to the **dense canopy and shadow effects** common in fruit trees. Additionally, Sentinel-2's 10–20 m resolution may include background soil or partial tree canopy in the same pixel, especially near the orchard edges, leading to a small dilution of the true chlorophyll signal.
Despite this, the **relative differences between samples** are well maintained, which is highly encouraging for remote sensing applications. This means that even though absolute values are slightly lower, the technology can still **track changes, growth patterns, and relative health status** of guava orchards over time.
This result is particularly valuable because Guava has a **high economic value** and is vulnerable to drought, fungal attacks, and nutrient deficiencies. Early detection of stress through satellite data can enable timely interventions, such as precision irrigation or targeted fertiliser application.
In conclusion, the chlorophyll estimation results for guava validate the use of remote sensing for **orchard health assessment**, and open possibilities for **large-scale, low-cost monitoring** of fruit crop performance in regions like Malegaon.

3. Fodder Crop Results – Analysis and Interpretation
Fodder is a major cash crop in the Malegaon region and plays a significant role in the local agricultural economy. Unlike guava, fodder is an **annual crop** with lateral **leaves** and a **high biomass production**.
The fodder crop was studied in fields located between **20.524020°N to 20.522937°N latitude** and **74.527371°E to 74.526793°E longitude**. These areas were carefully selected during the field survey for their active crop stage, uniform planting, and minimal interference from weeds or surrounding tree cover. The plants were in their **pre-flowering vegetative phase**, during which chlorophyll content tends to peak as leaves are fully developed and photosynthetic activity is at its highest.
During the fieldwork, **leaf samples were collected and subjected to laboratory** for further analysis using a UV-Vis spectrophotometer. The values, recorded in microgram per square cm(**μg/cm²**), were notably higher. The **leaf colour**

appeared dark green, a typical sign of nitrogen-rich, healthy growth.
For satellite-based comparison, reflectance data from the same coordinates were extracted from the **Sentinel-2 image dated 24 Nov 2024**, using SNAP. After applying necessary resampling and cropping image subsets for the fields, **chlorophyll ab and other biophysical values were estimated.**
The results for the cotton crop are presented below:

Sample ID	**Latitude**	**Longitude**	**Chlorophyll conc. from Satellite (µg/cm^2)**	**Chlorophyll conc. from Field (µg/cm^2)**
F1	74.52730	20.52405	39.1462	43.5466
F2	74.52730	20.52387	27.6763	30.5793
F3	74.52679	20.52332	31.5545	40.7923
F4	74.52679	20.52340	37.9722	45.4665
F5	74.52679	20.52345	44.1904	49.1975

The pattern observed here mirrors what was seen in wheat and Guava — the satellite-derived chlorophyll values were slightly lower than the field readings but **followed the same trend consistently**. The strongest correlation was found in cotton, where field and satellite measurements **aligned very closely.**This can be credited to the crop's uniform leaf distribution and the open canopy structure, which allows better sunlight reflection and reduces the chances of shadow-based errors in reflectance.
The **highest field chlorophyll reading**, 49.1975 **µg/cm^2** (Sample F5), also corresponded to the highest satellite-derived value of 44.1904 **µg/cm^2**. Likewise, the lowest field value of 30.5793 **µg/cm^2** (Sample F2) aligned well with the satellite estimate of 27.6763 **µg/cm^2**. This high degree of similarity indicates that **Sentinel-2 imagery is particularly well-suited** for broadleaf row crops like Guava, especially when the canopy is open and leaves are exposed to direct sunlight.
From a practical perspective, these results confirm that wheat and fodder are **excellent candidates for satellite-based health monitoring**, particularly in regions like Malegaon, where accurate, cost-effective, and timely crop insights are needed. Farmers can benefit greatly from early detection of nutrient deficiencies or water stress using this method. In fact, if implemented at scale, this approach could help optimise fertiliser usage, reduce environmental damage, and increase yield.

Discussion

This study was conducted to verify how accurately **Sentinel-2 satellite imagery** can estimate **chlorophyll content** when compared to values obtained manually from field measurements. The analysis focused on three commonly cultivated crops in the Malegaon region: **wheat, guava and fodder**.
The findings revealed a **strong and consistent correlation** between satellite-derived chlorophyll values and field-based observations across all three crops. While the values estimated from satellite data were **slightly lower than the manually recorded values**, the **overall pattern and trend were very similar**. This slight difference in values is expected and can be attributed to a few technical and environmental reasons:

- **Atmospheric Interference:** Even after applying atmospheric correction using the **Sen2Cor module** in SNAP, small amounts of **residual haze, cloud vapour, or air moisture** may remain in the atmosphere, slightly affecting the accuracy of reflectance values captured by the satellite.
- **Mixed Pixel Effect:** In some cases, a single pixel in the satellite image may not represent pure vegetation. It could include **a mix of leaf, soil, shadow, weed, or even tree branches**, especially in less uniform fields like guava orchards. This mixed reflectance can reduce the estimated chlorophyll value.
- **Sensor Resolution Limitations:** Although Sentinel-2 provides **high-resolution imagery (10–20 m)**, it still cannot match the fine detail captured during **close-range field sampling**, which measures individual leaves. Thus, slight variations in chlorophyll may not be detected in satellite data.

Besides chlorophyll concentration, the other biophysical parameters were also well estimated and show accurate values for healthy crops. The table below shows the entire range of all the parameters for the area of interest.

Biophysical Parameter	**Chlorophyll content (µg/cm^2)**	**Canopy Water Content CWC (g/m^2)**	**Fractional Vegetation Cover FVC**	**Leaf Area Index LAI**	**Fraction of absorbed photosynthetically active radiation Fapar**

Max value	66.1956	0.03436	0.506114	1.5031	0.585796
Min value	13.0405	0.012211	0.154659	0.3597	0.243541

— were all well within the **biologically expected ranges** reported in existing agricultural literature. This strengthens the reliability of using **spectral reflectance data from satellites** for biophysical parameters estimation in agricultural applications.

The graph below shows all the biophysical parameters, viz. LAI, CWC, FVC, and fapar for the entire Area Of Interest(AOI).

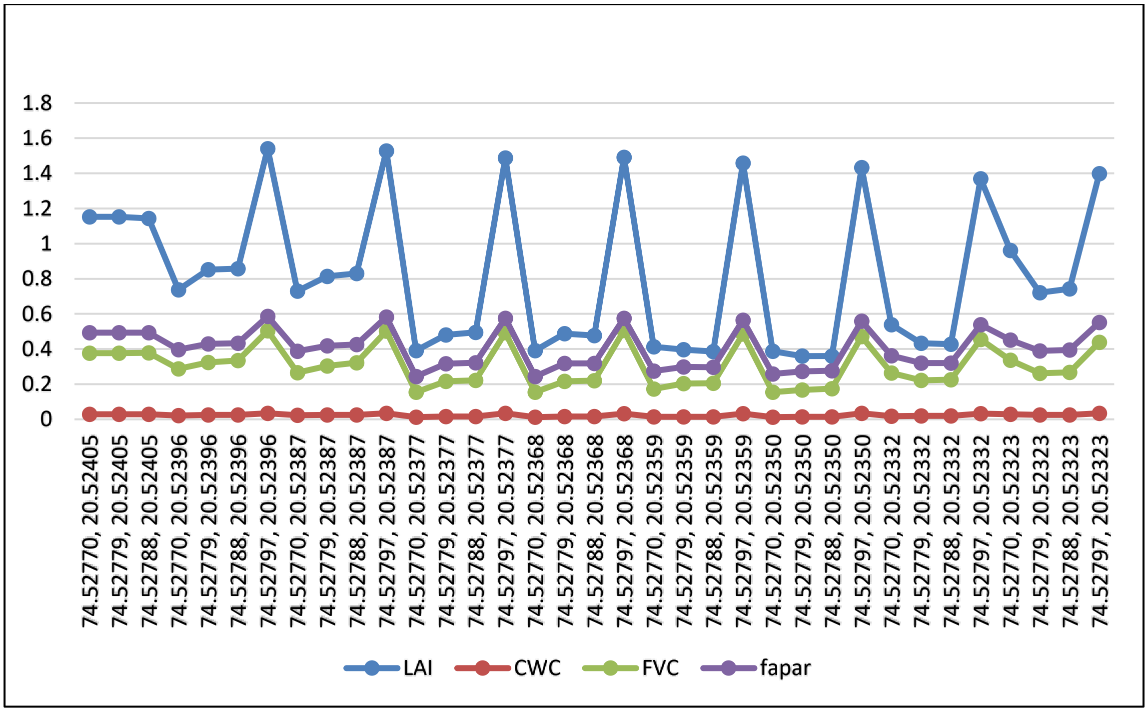


Fig. Graph of biophysical parameters vs Location(Latitude and Longitude)

The graph below shows the total Chlorophyll ab concentration for the whole area of interest estimated from the Sentinel-2 image at the SNAP platform.

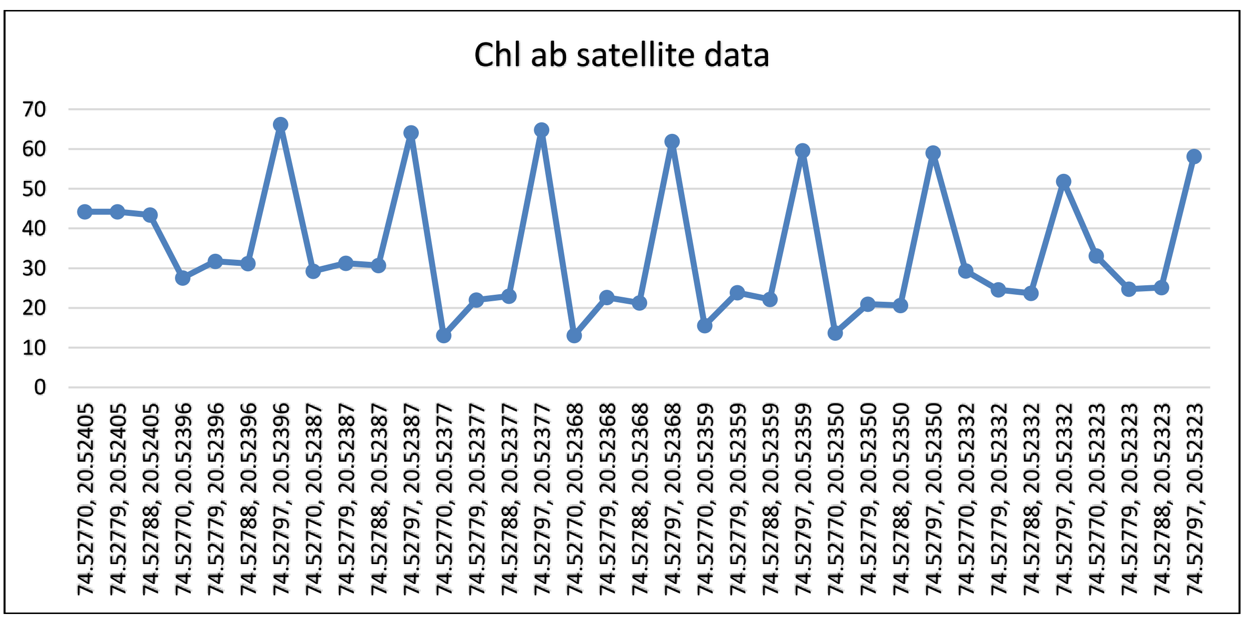


Fig. Chlorophyll ab concentration Vs Location(Latitude, Longitude)

The comparative graph below illustrates the difference and trend between field and satellite-derived chlorophyll values for all three crops. It shows a **line graph that** visually compares the chlorophyll values obtained from both methods for all three crops. It clearly shows that:

- The **overall trend** is the same across all sampling points,
- Satellite values are slightly lower but follow **almost the same rising and falling pattern** as the field measurements,
- There is a **crop-wise consistency**, indicating that even diverse crop types (with different leaf shapes, canopy densities, and planting styles) can be effectively monitored using this method.

This graphical representation not only supports the statistical reliability of satellite estimation but also highlights the **practical usability** of this technique in **real-world farming scenarios**, especially for monitoring crop health in semi-arid regions like Malegaon.

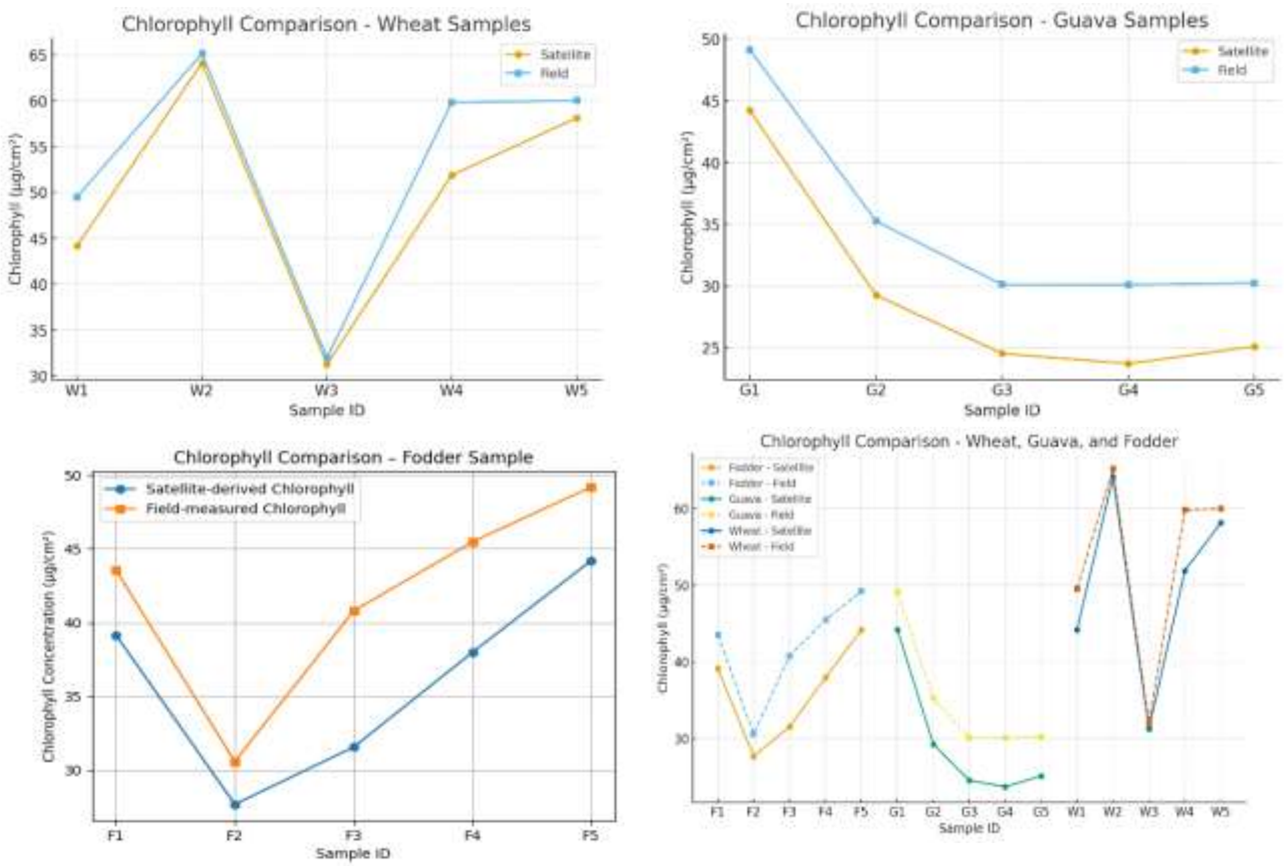


Fig. chlorophyll conc. Comparison graph for all three crop sample

The **comparative graph** illustrates the chlorophyll content recorded through **manual field measurements** and that estimated using **Sentinel-2 satellite imagery** processed through SNAP software for all three crops, and then combined graph is also there for comparing chlorophyll values for each crop.

It is obvious from the graph that **field-measured values are slightly higher** across all three crops, while **satellite-derived values are consistently lower but follow the same trend**. This small difference between the two sets of values is expected, given the nature of remote sensing and satellite resolution limitations, which cannot capture minute variability at the leaf level. Nevertheless, the bar heights show a **close parallel**, reinforcing the **validity and reliability** of using spectral reflectance data for estimating crop chlorophyll levels.

In the case of **Wheat**, the graph shows that chlorophyll content ranges from around **31.9752 µg/cm^2 to 65.1254 µg/cm^2** in field data, while satellite estimates range from **31.2707 µg/cm^2 to 64.0924 µg/cm^2**. Although the satellite bars are slightly shorter, they rise and fall in the same pattern as the field data, indicating accurate trend recognition.

For **Guava**, which has a more complex canopy structure, the chart reveals a similar pattern. Field values range between **30.1123 µg/cm^{2}and 49.0932 µg/cm^2**, while the satellite-derived values range from **23.722 µg/cm^{2}to 44.1932 µg/cm^2**. Despite the slightly greater variation, the satellite readings still mirror the relative highs and lows of the field results.

In **Fodder**, the highest chlorophyll levels were recorded, with field data ranging from **30.5793 µg/cm^{2}to 49.1975 µg/cm^2**, and satellite estimates ranging from **27.6763 µg/cm^{2}to 44.1904 µg/cm^2**. The strong agreement between the two data sources is clearly visible in the chart, especially in guava, where broad leaves and open canopies provide cleaner reflectance signals.

Overall, the figure powerfully demonstrates the **close agreement in pattern and trend** between both methods of chlorophyll estimation. Even though absolute values differ slightly, the **direction, order, and magnitude of variation**

remain consistent. This makes satellite-derived chlorophyll estimation a **reliable, scalable, and field-applicable method** for monitoring crop health, especially when used in combination with limited field sampling for validation.
Such visual representation further strengthens the conclusion that **Sentinel-2 imagery**, when processed correctly, offers **practical value for precision agriculture**, especially in diverse crop systems and semi-arid environments like Malegaon.

Conclusion

This study successfully demonstrated the effectiveness of using **satellite imagery**, specifically from **Sentinel-2**, for estimating crop biophysical parameters, especially **chlorophyll content,** using **PROSAIL Model** in major crops grown in the winter season in the **Malegaon region** of Maharashtra. By comparing satellite-based reflectance values with direct **field measurements**, we were able to validate that **spectral reflectance data**, when properly processed, can reliably indicate **plant health and chlorophyll levels**.
Three widely cultivated crops— **wheat, guava, and fodder**—were selected for analysis. Fieldwork involved recording accurate GPS coordinates and measuring chlorophyll content using a chlorophyll meter. The same locations were identified in the Sentinel-2 image dated **24 Nov 2024**, and chlorophyll estimates were computed using standard **absorbance-based formulas** after necessary pre-processing in **SNAP software**.
The results across all three crops showed a **strong positive correlation** between the chlorophyll values measured in the field and those derived from satellite data. Although the satellite estimates were Consistently **slightly lower**, this variation was expected and can be attributed to factors like **atmospheric interference, mixed pixel effects**, and **resolution limits** of the satellite sensor.
Despite these minor differences, the **trend in chlorophyll levels** was well-preserved in satellite readings. Areas with high chlorophyll in the field also showed high reflectance-based values, and vice versa. This indicates that **Sentinel-2 imagery** can be used with confidence to monitor changes in crop condition over time, especially during critical growth stages.
The other biophysical parameters also show reliability with crop health and condition, and are in good agreement with the standard values.
From a practical point of view, this method offers a **low-cost, scalable, and non-destructive alternative** to traditional field surveys. It allows **farmers, agronomists, and government planners** to assess crop health over large areas, detect early signs of stress, and make **timely management decisions**.
In regions like Malegaon, where **water availability and input efficiency are crucial**, such tools can be a game-changer in promoting **precision agriculture and sustainable farming practices**.
In conclusion, the integration of **remote sensing technology with ground truth data** has great potential in Indian agriculture. It not only improves monitoring efficiency but also contributes towards **resource conservation, risk reduction, and better crop productivity**. Future work can explore integrating weather data, soil maps, and machine learning models to further enhance accuracy and decision-making support for farmers and policymakers alike.

Future Scope and Study

The next step after this research work will be the ground truth data collection for other biophysical parameters like LAI, CWC, FVC and fapar and their comparison with satellite data, which is not done in this work due to certain circumstances and unavailability of devices and techniques. This will provide a more accurate status of vegetation health and condition, and will be very useful for farming applications in large croplands and also the remote areas.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my Research Guide for his continuous guidance and encouragement throughout this research.
I am also thankful to the Department of Physics at Late B.G. Kabra College of Arts & Science for their support in laboratory work.
I extend my gratitude to the European Space Agency (ESA) for providing access to Sentinel-2 satellite data through the Copernicus Open Access Hub, and to the developers of SNAP software, QGIS software for making such a powerful image processing tool freely available for scientific use.
Special thanks to the local farmers of Malegaon who allowed field access to their farms for sample collection and contributed valuable on-ground insights.
Lastly, I am grateful to my family and peers for their support and motivation during the entire research process.

References

1. Rouse et al. (1974) introduced the concept of NDVI as a simple yet powerful way to monitor vegetation health using satellite imagery, which laid the groundwork for our index-based analysis.
2. Gitelson and Merzlyak (1997) explored remote methods for estimating chlorophyll content in leaves, providing foundational equations that were adapted in this study for Sentinel-2 reflectance bands.
3. The work by Delegido and colleagues (2013) on red-edge spectral indices helped inform our approach to interpreting chlorophyll signals in crops with varying canopy structures.
4. Drusch et al. (2012) provided a comprehensive overview of Sentinel-2's capabilities, which was instrumental in

understanding its multispectral band applications for agricultural monitoring.
5. The Sentinel-2 User Handbook, published by the European Space Agency (ESA, 2024), was referenced extensively to understand band configurations, resolutions, and data processing steps.
6. Imagery used in this research was downloaded from the Copernicus Open Access Hub (2024), a freely accessible resource that supports researchers with multispectral satellite data.
7. Image preprocessing and vegetation index calculations were conducted using ESA's SNAP software (2024), which remains one of the most accessible and versatile platforms for Sentinel-2 analysis.
8. Baret and Guyot (1991) discussed the use of vegetation indices for estimating plant parameters such as LAI and APAR, insights from which helped guide the interpretation of index results.
9. The study by Zarco-Tejada et al. (2003) on chlorophyll fluorescence and red-edge effects gave us an understanding of the double-peak feature often seen in healthy vegetation spectra.
10. For comparative insight into similar agricultural landscapes, Kaur and Sharda (2021) used Sentinel-2 imagery to assess crop conditions in Indian farmlands, highlighting practical outcomes of index-based monitoring.