CANOPY NITROGEN ESTIMATION ON COTTON PLANT USING SATELLITE IMAGERY

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ABSTRACT:

The optimization of nitrogen (N) management is becoming a key challenge to enhance crop yield production while protecting the environment. Analysis of canopy N content in crop plants is used as insights for fertilization management, in which actions can be taken to optimize N fertilizer usage. Traditionally, lab chemical processing is used to measure the crop plant's nutrient content. However, the collection of leaf samples from the field is labour intensive, and it would be costly to increase sampling frequency. Thus, this approach may not be the most optimal for large plantations. Remote sensing applications in agriculture have been widely studied. This study aims to evaluate the potential of using Sentinel 2 imagery to predict canopy N content, as an alternative wide scale method as compared to traditional methods. A cotton plantation with about 50 square km area in the state of Mato Grosso, Brazil, was used as the case study. About 180 samples across the cotton plantation were collected between March and April 2022 and the N contents of the crop plants were measured using lab chemical processes. Sentinel 2 images within 15 days of the sampling dates were retrieved from ESA's Copernicus Open Access Hub. This study proposes a Random Forest (RF) regression algorithm for the generation of an N prediction model. About 52 vegetation indices (VIs) were extracted as the features for model training, such as Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). RF model allows easy measurement of the relative importance of each feature with respect to the prediction to achieve a good performance. Validation is done by using mean absolute error (MAE) and mean absolute percentage error (MAPE) to evaluate the prediction accuracy against the ground truth, which resulted to be 3.418 g/kg and 9.29% respectively. Finally, this study analyses the performance of the canopy N prediction model and assesses its ability as an alternative to traditional lab chemical sampling processes.

1. INTRODUCTION

Increasing global demand for agricultural products have resulted in more intensive farming that causes drains nutrients from the soil (Purwanto & Alam, 2019). Application of fertilizer replaces the nutrients for crop uptake which otherwise would have been insufficient. However, over-fertilisation of crop land occurs worldwide and may cause environmental issues due to surface run-off into the natural environment (Ritchie, 2021; Sishodia et al., 2020). Furthermore, application of excess fertiliser contributes to additional costs. This pushes for a need to identify the optimal amount of fertiliser to minimise cost as well as maintaining yield. This optimal amount depends on the plant status and thus the requirement to have an accurate estimate of the plant nutrient status.

Nitrogen is an important element in the plant, and is present in chlorophyll, amino acids and hence protein, nucleic acids, plant tissue, etc (Buchholz, 2022). Traditionally, N level can be obtained via lab chemical processing, however, this process takes time and increases the operational costs (Farella et al., 2022). Furthermore, the sampling results only applies for that set of leaf samples and does not represent the entire crop field. There is a need to consider alternate methods of estimating leaf nutrient that is cheaper and faster.

Satellite-based remote sensing provides an advantage in wide area monitoring and have been used for many different applications in agriculture, such as land use and crop classification, soil health and moisture, and vegetation health (Sishodia et al., 2020). Satellites such as European Space Agency's Sentinel 2 provides global coverage over land once every 5 days and have a wide imaging swath of 290 km (Sentinel-2). Sentinel 2 L2A product has 12 bands ranging from visible to short wave infrared at spectral resolutions ranging from 10m to 60m. It is provided for public access and is atmospherically corrected, hence it is a surface reflectance product. Band combinations – such as band ratios, normalised band differences, or more complex formulae – can be derived for different purposes. There are many indices derived for agricultural purposes, such as Normalised Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). These vegetation indices (VI) have their own advantages and limitations. One example is the usefulness of NDVI to determine broadly the vigour of a vegetated area, however it faces an oversaturation issue where NDVI value loses sensitivity beyond a vegetation density (Pettorelli et al., 2005).

Machine learning can be used to estimate nitrogen levels on crop leaves using satellite imagery by collecting data, extracting relevant features, training a machine learning model, and validating the model. Marang et al. (2021) proposed hybrid random forest regression, DBSCAN, and PCA to predict N level on cotton crop using hyperspectral UAV and sentinel imagery. Huang et al. (2015) estimated rice nitrogen status based on satellite imagery. R-squared was used to compute relationship between vegetation indices and rice N status. Moreover, Tan et al. (2020) proposed partial least square and remote sensing imagery to predict protein content.

Random forest (RF) regression is one of the common machine learning methods which have been used in estimation of foliar nitrogen levels (Abdel-Rahman et al., 2012; Soltanikazemi et al., 2022). RF is an ensemble method which uses a decision tree as a base estimator. It allows for easy measurement of the relative importance of each feature with respect to the prediction, hence achieving a good performance. In this study, we attempted to use RF regression model to estimate foliar nitrogen concentrations for cotton crops in Brazil. We want to validate the performance of applying RF regression model on selected indices based on Sentinel 2 and determine the limitations of the model.

2. STUDY AREA AND DATA COLLECTION

In this paper, field experiments were conducted from February to April 2022 over a cotton plantation in the state of Mato Grosso, Brazil with about 50 square km area, as shown in Figure 1. Leaf samples were collected during the vegetative and flowering stage of the cotton plants, between 70 to 120 days after emergence. The sampling process involve by first identifying a sampling coordinate (latitude, longitude) within the plantation. Leaf samples are then collected randomly within a 10m radius from the sampling coordinate. This process was iterated across different sampling coordinates and dates. Afterwards, the samples were handled by a professional vendor to measure the nitrogen content using chemical laboratory equipment, carried out with standardized procedure. The measured leaf nitrogen concentration of the leaf samples was then provided as g/kg. In this study, 180 samples were collected and used to generate and validate our model. The statistics of the sampled nitrogen concentration is as shown in Table 1 below.



Figure 1. Cotton Plantation Area

Mean	Standard Deviation	Min	Max
38.3	5.15	23.5	52.6

 Table 1. Statistics of Nitrogen samples in g/kg

We collected cloud-free Sentinel-2 L2A data that fall within 15 days from the sample date for each sampling coordinate. L2A products were used for our processing as the atmospheric effects were removed. We then up-sampled all bands to 10m spatial resolution, before extracting the 3x3 context pixels centred on the sampling coordinates. Vegetation indices (VIs) were computed to obtain the percentage of vegetation cover, amount of

chlorophyll content, leaf area, and so on (As-Syakur et al. 2012; Brecht 2018; Broge and Leblanc 2001; Chen 1996; Duong et al. 2017; El-Shikha et al. 2008; Frampton et al. 2013; Gitelson et al. 2002; Hiphen-plant 2022; Huang et al. 2012; Main et al. 2011; Metternicht 2003; NDRE index 2023; Pro.arcgis; Rasul et al. 2018; Sentinel Hub; Vincini et al. 2008; Waqar et al. 2012; Xu 2006; Zhao and Chen, 2005). A total of 52 VIs were computed to get handcrafted features, as described in the Appendix. After which, 52 VIs and 12 bands were deployed as the feature inputs to the RF model.

3. METHOD

Figure 2 shows the overall flowchart of the proposed method, including pixel extraction, feature extraction, and RF regression model. Firstly, Sentinel-2 images and sample coordinates were used to retrieve sampled foliar nitrogen values and their respective pixels. The 52 VIs were then computed. Next, the training dataset was generated from the 12 bands and 52 VIs. The best hyperparameters of the RF model were chosen with reference to the training dataset, with the aid of Random Search CV optimization algorithm. Table 2 shows the hyperparameters that were fed into the optimization algorithm. The dataset was then incorporated into the model for training.



Figure 2. Overall Flowchart

Parameters	Hyperparameters values
Max depth	[10, 20, 30, 40, 50, 60, 70, 80, 90, 100]
Max features	['auto', ''sqrt]
Min sample leaf	[1, 2, 4]
Min sample split	[2, 5, 10]
N estimators	[200, 400, 600, 800, 1000, 1200, 1400, 1600, 1800, 2000]

 Table 2. Settings for Hyperparameter Values as Input to the Random Search CV Algorithm

4. PERFORMANCE EVALUATION

Figure 3 shows the histogram of the dataset where we observe most N values ranged between 33 and 47 g/kg, therefore we assumed that values beyond this range were extreme values. In the experiment, we split the dataset randomly into 80% training and 20% testing with respect to the observed value.



Figure 3. Histogram of Dataset

The optimized RF model was trained using the training dataset, generating the feature importance scores as shown in Figure 4 below. It was shown that the top 15 features were the most important on the N prediction, namely Band 11, Band 1, IRECI, Band 5, MNDWI, BRBA, CCCI_ALT, Band 12, Band 9, NDVI3, MCARI_ALT, BUI, Band 2, Band 3, and NPCI.



Figure 4. Random Forest Feature Importance

The model was further evaluated using the mean absolute error (MAE) and mean absolute percentage error (MAPE). MAE is a common metric used to evaluate the performance of prediction model by measuring the average absolute difference between the observed and predicted values. MAPE is similar to MAE, except the average absolute difference is being divided by the observed value before summation. The formulas of MAE and MAPE are as shown below:

$$MAE = \frac{1}{n} \sum_{i=1}^{n} \left| y_{actual} - y_{predicted} \right| \tag{1}$$

$$MAPE = \frac{100}{n} \sum_{i=1}^{n} \frac{|y_{actual} - y_{predicted}|}{y_{predicted}}$$
(2)

where n = number of samples $y_{actual} =$ observed value $y_{predicted} =$ predicted value

Figure 5 below depicts the prediction plot using training and testing data that gives a fit prediction for training data. According to our experiment, this study presents MAE of 3.418 g/kg, which is MAPE of 9.29% for the testing dataset.

We observe that the model is able to achieve a better performance for N prediction where the values fall within the middle range highlighted above. Poorer performance for the extreme values could be attributed to lack of training data in that range, and that training with an imbalanced dataset resulted in higher errors. In addition, it is believed that the model loses sensitivity at the extreme ends of the distribution and the dataset is still lacking features with high correlation to N. Increase in variance of N distribution and the size of the dataset can be an alternative solution in the future to overcome the overfitting issue. Moreover, hyperspectral (HS) images can be an option to increase the number of features available for training since they are more sensitive than S2A images, which are multispectral images.



Figure 5. Prediction Plot a). using Training Data, b). using Testing Data

5. CONCLUSION

This study proposed the use of Sentinel-2 imagery and machine learning method, specifically RF model, to predict the amount of N present in the canopy of the cotton crops, in hopes of replacing the traditional method, with the end goal to save cost and time. RF model was chosen since it could calculate which feature was important to the prediction to achieve a high accuracy, with the top 15 features being the most important on the N prediction to be Band 11, CSI, Band 1, IRECI, Band 5, MNDWI, BRBA, CCCI_ALT, Band 12, Band 9, NDVI3, MCARI_ALT, BUI, Band 2, Band 3. The validation metric used was MAE which resulted to be 3.418 g/kg, which was MAPE of 9.29% for the testing dataset. While MAE is considerably low, more could be done since MAE was mostly contributed by the inaccurate prediction of extreme N values. Improvements such as using hyperspectral imagery instead of Sentinel-2 imagery and using different VIs of different feature importance based on different methods could be done. Even though VIs among different methods could be of different feature importance, stacking them with the consideration of different methods could prevent overfitting and should be used to monitor agricultural fields to improve classification accuracy. In addition, boosting the dataset with more data, especially in the extreme range, would help to resolve the imbalanced dataset issue.

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APPENDIX

Sentinel-2	Description	Notations
L2A bands		
Band 1	Coastal or Aerosol	Co
Band 2	Blue	В
Band 3	Green	G
Band 4	Red	R
Band 5	Vegetation red edge	RE1
Band 6	Vegetation red edge	RE2
Band 7	Vegetation red edge	RE3
Band 8	Near Infrared	NIR
Band 9	Narrow NIR	NNIR
Band 10	Water vapour	WV
Band 11	SWIR	S1
Band 12	SWIR	S2

 Table 3. Sentinel-2 L2A bands description

No	Indices	Full name	Formula Based on S2 bands
		Normalised	(Marta)
1	NDVI	Difference	NNIR - R
1	ND VI	Vegetation	$\overline{NNIR + R}$
		Index Modified Soil	
	MSAVI	Modified Soil	(
2	2	Vegetation	$\frac{2\times NNIR+1-\sqrt{(2\times NNIR+1)^2+8(NNIR-R)}}{2}$
		Index	
		Visible	
3	VARI	Atmospherica	$\frac{G-R}{R}$
		Index	G + R - B
		Modified	
4	MNDW	Normalized	G-S1
4	Ι	Difference	$\overline{G+S1}$
		Water Index	NNUD C1
5	NDMI	Normalized Difference	$\frac{NNIR - SI}{NNIR + SI}$
		Burn Area	$\frac{NNIR + SI}{1}$
6	BAI	Index	$(0.1-R)^2 + (0.06 - NNIR)^2$
		Normalized	
7	NDBI	Difference	S1 - NNIR
,	TID DI	Built-up	S1 + NNIR
		Enhanced	
8	EVI	Vegetation	$2.5 \times \frac{NNIR-R}{1000}$
-		Index	$NNIR+(6\times R-7.2\times B)+1$
		Enhanced	NNIR - R
9	EVI2	Vegetation	$2.5 \times \frac{1.111}{NNIR + 2.4 \times R + 1}$
		Index	
		Soil Adjusted	NNIR – R
10	OSAVI	Vegetation	$\overline{NNIR + R + 0.16}$
		Index	
		Soil Adjusted	
11	SATVI	Total Vegetation	$\frac{S1-R}{S1+R+L} \times (1+L) + \frac{S2}{2}$
		Index	51 T K T L L
42	DCI	Bare Soil	R + B - G
12	B21	Index	$\overline{R + B + G}$
		Normalized	NNIR - S1
13	NDWI	Difference Water Index	$\overline{NNIR + S1}$
		Structure	
	CIDI	Insensitive	NNIR – CO
14	SIPI	Pigment	NNIR + R
		Index	C1
15	MSI	Moisture	51
		Green	NNIR
		Normalized	
16	GNDVI	Difference	$\frac{NNIR - G}{NNIR + G}$
		Vegetation	NNIR + G
		Index	$(S1 \pm D) = (NNID \pm D)$
17	BI	Bare Soil	$\frac{(31 \pm N) - (NNIK \pm D)}{(S1 \pm D) + (NNID \pm D)}$
		Dry Bare Soil	$\frac{(SI + K) + (NNK + B)}{SI - G}$
18	DBSI	Index	$\frac{1}{S1+G} - NDVI$
19	NBAI	Normalised	$S_{2}^{2} - S_{1}^{2}/G$
		Built-Up	$\frac{52}{52+51/6}$
		Area Index	52 1 51/0
20	BRBA	for Built-Up	R
	DIND/I	Araa	$S\overline{1}$

21GIGreenness Index $\frac{G}{R}$ 22MSRModified Simple Ratio $SR - 1$ $\sqrt{SR - 1}$ 23SRSimple Ratio $NNIR/R$ 24RDVIRenormalised Uriference $\frac{NNIR - R}{\sqrt{NNIR + R}}$ 25NRIReflectance Index $\frac{G - R}{G + R}$ 26TCARIReflectance Absorption and Reflectance $\frac{G - R}{G + R}$ 27PSRIPlant Senescence $\frac{R - B}{RE2}$ 28NPCIPlant Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 29MCARI altAbsorption in Reflectance $\frac{R - Co}{R + Co}$ 30MTCIModified Chlorophyll ratio Index $((RE1 - R) - 0.2 \times (RE1 - G) \cdot (\frac{RE1}{R}))$ 31MCARI altAbsorption in Reflectance $\frac{R - Co}{R + Co}$ 33CCL_aMerris Chlorophyll Index (alternate) $((RE1 - R) - 0.2 \times (RE1 - G) \cdot (\frac{RE1}{R}))$ 34ACARI Absorption in Reflectance $\frac{(NNIR - RE2)}{(RE2 + R)}$ 35PVRCanopy Chlorophyll NIR + R $\frac{(NNIR - RE2)}{(NNIR + RE2)}$ 34AVIVegetation Index $\frac{NNIR - R}{G^2}$ 35PVRChlorophyll Ratio $\frac{\rho \times NNIR - R}{G + R}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - R}{RE1}$ 37ARVI2Modified Vigetation Index $\frac{ONIR - R}{NNR + R}$ 38mNDVINDVI $\overline{NNIR - R} + 2 \times CO$	No	Indices	Full name	Formula Based on S2 bands
21GIIndex \overline{R} 22MSRModified Simple Ratio $\overline{SR} - 1$ $\sqrt{SR} - 1$ 23SRSimple Ratio $NNIR/R$ 24RDVIRenormalised Difference 			Greenness	G
22MSRModified Simple Ratio $SR - 1$ $\sqrt{SR - 1}$ 23SRSimple Ratio $NNIR/R$ 24RDVIDifference Vegetation Index $NNIR - R$ $\sqrt{NNIR + R}$ 25NRIReflectance Index $\frac{G - R}{G + R}$ 26TCARITransformed Chlorophyll Absorption and Reflectance Index $\frac{G - R}{G + R}$ 27PSRISenescence Reflectance Index $\frac{R - B}{RE2}$ 28NPCIPlant Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 29MCARI (Alternate)Modified Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{(INIR - RE2)}{(RE1 - R) - 0.2(NRI - G)(\frac{RE1}{R}))}$ 31MCARI (Alternate)Merris Terrestrial Chlorophyll Index $\frac{(INIR - RE2)}{(RE2 + R)}$ 32CCCL_a CLlorophyll It CLlorophyll CLlorophyll CLlorophyll CLlorophyll COntorphyll Reflectance Index $\frac{(INIR - RE2)}{(RE2 + R)}$ 33CVICanopy Vegetation Index $\frac{(INIR - RE2)}{(NNIR + RE2)}$ 34AVIVegetation Index $\frac{G - R}{(NNIR + RE2)}$ 35PVRAdvanced Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{\rho_{RE1}}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - R \times Co}{R + C}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - R \times Co}{R + R}$ 36NNVINDVINDVI $\frac{NNIR - R \times 2 \times CO}{NNIR + R}$ </td <td>21</td> <td>GI</td> <td>Index</td> <td>\overline{R}</td>	21	GI	Index	\overline{R}
22MSRSimple Ratio $\sqrt{SR - 1}$ 23SRSimple RatioNNIR/R24RDVIRenormalised Difference Vegetation IndexNNIR - R $\sqrt{NNIR + R}$ 25NRIReflectance Index $\frac{G - R}{G + R}$ 26TCARIPlant Reflectance Index $\frac{G - R}{G + R}$ 27PSRIPlant Senescence $\frac{R - D}{RE2}$ 28NPCIPlant Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 29MCARI Absorption and ReflectanceModified Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 30MCCIIMetris Terrestrial Chlorophyll Index $\frac{((RE1 - R) - 0.2 \times (RE1 - G) + \binom{RE1}{R})}{(RE2 + R)}$ 31MCARI Absorption in Reflectance Index $\frac{R - Co}{R + Co}$ 32CCCL_a Chlorophyll Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ 33CVICanopy Vegetation Index $\frac{(NNIR - RE2)}{(NIR - RE2)}$ 34AVIVegetation Index $\frac{(NNIR - RE2)}{(NIR - RE2)}$ 34AVIVegetation Index $\frac{G - R}{(NNIR + RE2)}$ 35PVRPhotosyntheti Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{G^2}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - R \times Q}{P^{XRE1}}$ 37ARVI2NOVINOVI $\frac{NOVIR - R + 2 \times CO}{NOVIR + RE1}$ 38mNDVINDVI $\frac{NOVIR - R + 2 \times CO}{NOVIR + R + 2 \times CO}$	22	MOD	Modified	SR - 1
23SRSimple RatioNNIR/R24RDVIRenormalised Difference Reflectance Index $\frac{NNIR - R}{\sqrt{NNIR + R}}$ 25NRINitrogen Reflectance Index $\frac{G - R}{G + R}$ 26NRITransformed Chlorophyll Absorption Reflectance Index $\frac{G - R}{G + R}$ 27PSRISenescence Reflectance Index $\frac{R - B}{RE2}$ 28NPCIPigment Chlorophyll Absorption in alt $\frac{R - Co}{R + Co}$ 29MCARI altMorrise Chlorophyll Absorption in alt $\frac{(RE1 - R) - 0.2 (RE1 - G) (\frac{RE1}{R})}{(RE1 - R) - 0.2 (RE1 - G) (\frac{RE1}{R})}$ 30MCARI altModified Chlorophyll Absorption in Reflectance Index (alternate) $\frac{(R - Co}{R + Co}$ 31MCARI altMerris Chlorophyll Absorption in Reflectance Index (alternate) $\frac{((RE1 - R) - 0.2 (RE1 - G) + \frac{(RE1}{R}))}{(RE1 - R) - 0.2 (RE1 - G) + \frac{(RE1}{R})})$ 33MCARI altMerris Chlorophyll Absorption in Reflectance Index $\frac{((NNIR - RE2)}{(RE2 + R)}$ 34MCARI Advanced Vegetation Index $\frac{((NNIR - RE2)}{(NNIR - R)}$ 35PVR RAVICAlorophyll Vegetation Index $\frac{G - R}{G + R}$ 36RRECI RatioInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{G + R}$ 37ARVI2Ily Resistant Vegetation Index $-0.18 + 0.17 (\frac{NNIR - R}{NNIR + R})$ 38mNDVINDVI $\frac{NDVIR}{NDR + R} + 2 \times CO}$	22	MSK	Simple Ratio	$\sqrt{SR-1}$
24RDVIRenormalised Difference Vegetation $NNIR - R$ $\sqrt{NNIR + R}$ 25NRINitrogen Reflectance Index $\frac{G - R}{G + R}$ 26NRITransformed Chlorophyll Absorption Reflectance Index $\frac{G - R}{G + R}$ 27PSRISenescence Reflectance Reflectance Index $\frac{R - B}{RE2}$ 28NPCIPlant Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 29MCARI altModified Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 30MTCIMerris Chlorophyll ratio Index (alternate) $((RE1 - R) - 0.2 \times (RE1 - G) + (\frac{RE1}{R}))$ 31MCARI altModified Chlorophyll Index (Chlorophyll Reflectance $((RE1 - R) - 0.2 \times (RE1 - G) + (\frac{RE1}{R}))$ 31MCARI altMerris Chlorophyll (Chlorophyll Index (Chlorophyll (RE2 + R)) $((RE1 - R) - 0.2 \times (RE1 - G) + (\frac{RE1}{R}))$ 31MCARI altMerris Chlorophyll (Chlorophyll (Chlorophyll (RE2 + R)) $((RE1 - R) - 0.2 \times (RE1 - G) + (\frac{RE1}{R}))$ 32CCCL_a Chlorophyll IndexModified (Chlorophyll (RE2 + R)) $((RNIR - RE2))$ ($(RZ + R)$)33CVICClorophyll Vegetation Index $((NNIR - RE2))$ ($(NNIR - RE2)$ ($(NNIR + R)$)34AVIVegetation Index $\frac{G - R}{(RRC1)}$ 35PVRChlorophyll Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{G^2}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - R \times R}{G^2}$ 35PVRIn	23	SR	Simple Ratio	NNIR/R
24RDVIDifference Vegetation Index $NNIR - R$ $\sqrt{NNIR + R}$ 25NRIReflectance Index $\frac{G - R}{G + R}$ 26NRITransformed Chlorophyll Absorption and Reflectance Index $\frac{G - R}{G + R}$ 27PSRIPlant Senescence Reflectance $\frac{R - B}{RE2}$ 28NPCIPlant Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 29MCARI altModified Chlorophyll ratio Index $\frac{R - Co}{R + Co}$ 30MTCIMerris Chlorophyll ratio Index (alternate) $\frac{((RE1 - R) - 0.2(RE1 - G) (\frac{RE1}{R}))}{(RE1 - R) - 0.2 \times (RE1 - G) (\frac{RE1}{R})}$ 31MCARI altModified Chlorophyll Reflectance Index (alternate) $\frac{((NNIR - RE2)}{(RE2 + R)}$ 33MTCIMerris Chlorophyll Reflectance Index $\frac{((NNIR - RE2)}{(RE2 + R)}$ 34MCARI altCanopy Chlorophyll Absorption in Reflectance Index $\frac{((NNIR - RE2)}{(NNIR + RE2)}$ 33CVIChlorophyll Content (Alternate) $\frac{((NNIR - RE2)}{(NNIR + RE2)}$ 34AVIChlorophyll Vegetation Index $\frac{G - R}{(NNIR + R)}$ 35PVRChlorophyll Ratio $\frac{Q - R}{G + R}$ 36IRECIIndex $-0.18 + 0.17 (\frac{NNIR - R}{(NNIR - R)})$ 37ARVI2Wegetation Index $-0.18 + 0.17 (\frac{NNIR - R}{(NNIR + R)})$ 38mNDVIModified Vegetation Index $-0.18 + 0.17 (\frac{NNIR - R}{(NNIR + R)})$			Renormalised	
24RDV1Vegetation Index $\sqrt{NNIR + R}$ 25NRINitrogen Reflectance Index $\overline{G - R}$ $\overline{G + R}$ 26TCARITransformed Chlorophyll Absorption and Reflectance Index $\overline{G - R}$ $\overline{G + R}$ 27PSRIPlant Senescence Reflectance Index $R - B$ $\overline{RE1}$ 28NPCIPigment Chlorophyll absorption in Reflectance Index $R - Co$ $\overline{R + Co}$ 28NPCIPigment Chlorophyll ratio Index $R - Co$ $\overline{R + Co}$ 30MCARI altMerris Terrestrial Chlorophyll Index $((RE1 - R) - 0.2 \times (RE1 - G) + (\overline{R}))$ 30MTCIMerris Terrestrial Chlorophyll Index $((RE1 - R) - 0.2 \times (RE1 - G) + (\overline{R}))$ 31MCARI altMerris Terrestrial Chlorophyll Index $((RE1 - R) - 0.2 \times (RE1 - G) + (\overline{R}))$ 31MCARI altMerris Terrestrial Chlorophyll Index $((RE1 - R) - 0.2 \times (RE1 - G) + (\overline{R}))$ 32CCCI_a IndexMerris Terrestrial Chlorophyll Reflectance Index $((NNIR - RE2))$ $(NNIR - RE1) - 0.2(NNIR - G)$ 33CVIContent (alternate) $((NNIR - RE1) - 0.2(NNIR - G))$ $\overline{RE1}$ 33CVIChlorophyll Chlorophyll Index $\sqrt{(NNIR - R)}$ $(NNIR + R)$ 34AVIVegetation Index $\sqrt{(NNIR - R)}$ $\overline{RE1}$ 35PVRPhotosyntheti c Vigour Ratio $\frac{P \times NNIR - p \times R}{G + R}$ $\frac{P \times RE2}$ 36IRECIIndex Chlorophyll Index $-0.18 + 0.17 (N$	24	DDI/I	Difference	NNIR - R
IndexIndex25NRINitrogen Reflectance $\frac{G-R}{G+R}$ $\frac{G-R}{G+R}$ 26TCARITransformed Chlorophyll Absorption and Reflectance $3[(RE1-R)-0.2(RE1-G)(\frac{RE1}{R})]]$ 27PSRISenescence Reflectance $\frac{R-B}{RE2}$ 28NPCINormalised Pigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ $\frac{R+Co}$ 29MCARI _altModified Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{((RE1-R)-0.2\times(RE1-G)\cdot(\frac{RE1}{R}))}{(RE2+R)}$ 31MCARI _altModified Chlorophyll Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ 33CCCI_a ItCanopy Chlorophyll Reflectance Index $\frac{(NNIR - RE2)}{(NNIR - RE2)}$ 34AVIChlorophyll Vegetation Index $\frac{(NNIR - RE2)}{(NNIR + R)}$ 35PVRChlorophyll Chlorophyll Index $\frac{\sqrt{(NNIR - RE2)}}{(NNIR + R)}$ 36IRECIAdvanced Vegetation Index $\frac{\sqrt{(NNIR - RE2)}}{(NNIR + R)}$ 36IRECIAdvanced Vegetation Index $\frac{\sqrt{(NNIR - RE2)}}{(NNIR + R)}$ 37ARV12Wegesistant Vegetation Index $-0.18 + 0.17(\frac{(NNIR - R)}{(NNIR - R)})$ 38mNDVIModified Chlorophyll $-0.18 + 0.17(\frac{(NIR - R)}{(NNIR + R)})$	24	RDVI	Vegetation	$\sqrt{NNIR + R}$
25NRINitrogen Reflectance Index $\frac{G-R}{G+R}$ $\frac{G+R}$ 26TCARITransformed Chlorophyll Absorption and Reflectance Index $_3[(RE1-R) - 0.2(RE1-G)(\frac{RE1}{R})]]$ 27PSRIPlant Senescence Reflectance Chlorophyll ratio Index $R-B$ RE228NPCIPlant Pigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ $RE12$ 29MCARI _altModified Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ $(RE1-R) - 0.2 \times (RE1-G) + (\frac{RE1}{R}))$ $(RE1-R) - 0.2 \times (RE1-G) + (\frac{RE1}{R}))$ 30MTCIModified Chlorophyll Absorption in Reflectance Index (alternate) $\frac{(NNIR - RE2)}{(RE2 + R)}$ $(RE1-R) - 0.2 \times (RE1-G) + (\frac{RE1}{R}))$ 31MCARI Absorption in Reflectance Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ $(RE1-R) - 0.2(NNIR - G)$ 32CCCLa (CLorophyll ItChlorophyll Chlorophyll Content (alternate)33CVIVegetation Index34AVINordified Chlorophyll Index35PVRPhotosyntheti c Vigour Ratio36IRECIEdge Chlorophyll Index37ARVI2Photosyntheti vegetation Index38mNDVIModified Chlorophyll Index38mNDVIModified Chlorophyll			Index	
25NRIReflectance Index $\overline{G+R}$ 26TCARITransformed Chlorophyll Absorption and Reflectance Index $3[(RE1-R) - 0.2(RE1-G)(\frac{(RE1)}{R})]$ 27PSRIPlant Senescence Reflectance Reflectance $\frac{R-B}{RE2}$ 28NPCIPigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 29MCARI _altModified Chlorophyll Reflectance Index $\frac{(RE1-R) - 0.2(RE1-G)(\frac{RE1}{R}))}{(RE1-R) - 0.2 \times (RE1-G) \cdot (\frac{RE1}{R}))}$ 30MTCIModified Chlorophyll Absorption in Reflectance Index (alternate) $\frac{(NNIR - RE2)}{(RE2 + R)}$ 31MCARI Absorption in Reflectance IndexMerris Terrestrial Chlorophyll NE1 $\frac{(NNIR - RE2)}{(RE2 + R)}$ 31MCARI Absorption in Reflectance Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ 32CCCLa ItChlorophyll Chlorophyll Chlorophyll Content (alternate) $\frac{(NNIR - RE2)}{(NNIR + RE2)}$ 33CVIVegetation Index $\frac{(NNIR - RE2)}{(NNIR + RE2)}$ 34AVIVegetation Index $\frac{p \times NNIR \times \frac{R}{G^2}}{RE1}$ 35PVRPhotosyntheti c Vigour Ratio $\frac{G-R}{G+R}$ 36IRECIEdge Chlorophyll Index $-0.18 + 0.17(\frac{(NIIR - R)}{(NIIR + R)})$ 37ARV12Wegistion Index $-0.18 + 0.17(\frac{(NIIR - R)}{(NIIR + R)})$ 38mNDVIModified Vegetation Index 2 $-0.18 + 0.17(\frac{(NIIR - R)}{(NIIR - R)})$			Nitrogen	G - R
26IndexIndexIndex26TCARITransformed Chlorophyll Absorption and Reflectance Index $3[(RE1 - R) - 0.2(RE1 - G)(\frac{RE1}{R})]$ $3[(RE1 - R) - 0.2(RE1 - G)(\frac{RE1}{R})]$ Reflectance27PSRIPlant Senescence Reflectance $R - B$ RE228NPCIPlant Chlorophyll ratio Index $R - Co$ $R + Co29MCARI_altModifiedChlorophyllReflectanceIndex((RE1 - R) - 0.2 \times (RE1 - G) \cdot (\frac{RE1}{R}))(RE1 - R) - 0.2 \times (RE1 - G) \cdot (\frac{RE1}{R}))30MTCIMerrisTerrestrialChlorophyllIndex((RE1 - R) - 0.2 \times (RE1 - G) \cdot (\frac{RE1}{R}))(RE2 + R)31MCARIAbsorption inReflectanceIndexMerrisTerrestrialChlorophyllIndex((NNIR - RE2))(RE2 + R)31MCARIAbsorption inReflectanceIndexContorphyllRE1((NNIR - RE2))(RE1 - R) - 0.2(NNIR - G)]RE132CCCI_aItCanopyChlorophyllContent(alternate)((NNIR - RE2))(NNIR + R)33CVICanopyVegetationIndex((NNIR - RE2))(NNIR + R)34AVIVegetationRatioNNIR \times \frac{R}{G^2}35PVRPhotosynthetic VigourIndexG - RG + R36IRECIPhotosynthetiChlorophyllIndex-0.18 + 0.17(\frac{(NIR - R)}{(NNIR + R)})37ARV12ModifiedChlorophyllNDVI(NNIR - R)NDVI38mNDVIModifiedVegetationNDVI$	25	NRI	Reflectance	$\overline{G+R}$
26TCARIInfansionied Chlorophyll and Reflectance Index $3[(RE1-R)-0.2(RE1-G)(\frac{RE1}{R})]]$ 27PSRIPlant Senescence Reflectance $\frac{R-B}{RE2}$ 28NPCIPigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 29MCARI - altModified Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 30MTCIMerris Chlorophyll Absorption in Reflectance Index $\frac{((RE1-R)-0.2 \times (RE1-G) \times (RE1))}{(RE1-R)-0.2 \times (RE1-G) \times (RE1))}$ 31MCARI - altModified Chlorophyll Index $\frac{((RNIR - RE2)}{(RE2 + R)}$ 30MTCITerrestrial Chlorophyll Absorption in Reflectance Index $\frac{((NNIR - RE2)}{(RE2 + R)}$ 31MCARI - Colorophyll IndexColorophyll Absorption in Reflectance $\frac{((NNIR - RE2)}{(RE1 - R) - 0.2(NNIR - G))}{(RE1 - R) - 0.2(NNIR - G)}$ 32CCCI_a ItCanopy Chlorophyll Absorption in Reflectance Index $\frac{((NNIR - RE2)}{(NNIR + R)}$ 33CVIColorophyll Vegetation Index $\frac{(NNIR - RE2)}{(NNIR + R)}$ 34AVIVegetation Index $\frac{(NNIR - RE2)}{(NNIR + R)}$ 35PVRAdvanced Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{G^2}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{p^{ARE1}}$ 37ARV12Ily Resistant Vegetation Index 2 $-0.18 + 0.17(\frac{NNIR - R}{NNIR + R})$ 38mNDVIModified NDVI $(NNIR - R + 2 \times CO)$			Index	
26TCARIAbsorption and Reflectance Index $3[(RE1-R) - 0.2(RE1-G)(\frac{RE1}{R})]]$ 27PSRISenescence Reflectance $\frac{R-B}{RE2}$ 28NPCIPigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 29MCARI altModified Chlorophyll Absorption in Reflectance $\frac{R-Co}{R+Co}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{((RE1-R) - 0.2 \times (RE1-G) \times (\frac{RE1}{R}))}{(RE2+R)})$ 31MCARI altModified Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2+R)})$ 31MCARI CCCI_a ItModified Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2+R)})$ 32CCCI_a ItCanopy Chlorophyll Absorption in Reflectance Index $\frac{((NNIR - RE2)}{(RE1-R) - 0.2(NNIR-G)]}$ 33CVIChlorophyll Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2+R)})$ 34AVIVegetation Index $\frac{(NNIR + RE2)}{(NNIR + R)}$ 35PVRChlorophyll Chlorophyll $\frac{\rho \times NNIR \times \frac{R}{G^2}}{\frac{\rho \times NNIR - \rho \times R}{\rho \times RE1}}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{\rho \times RE1}$ 37ARVI2NDYINDYI $-0.18 + 0.17(\frac{NNIR - R}{NNIR + R})$ 38mNDVINDVI \overline{NDYI} $\overline{NNIR - R + 2 \times CO}$			Chlorophyll	
26TCARIInstant and and Reflectance Index $3[(RE1-R) - 0.2(RE1-G)(\frac{RE1}{R})]$ 27PSRIPlant $\frac{R-B}{RE1}$ 28NPCIPigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 29MCARI _altModified Chlorophyll Absorption in Reflectance Index (alternate) $\frac{(RE1-R) - 0.2 \times (RE1-G) \times (\frac{RE1}{R}))}{(RE1-R) - 0.2 \times (RE1-G) \times (\frac{RE1}{R}))}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{((RE1-R) - 0.2 \times (RE1-G) \times (\frac{RE1}{R}))}{(RE2+R)}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2+R)}$ 31MCARI Absorption in Reflectance Index $\frac{((NNIR - RE1) - 0.2(NNIR - G)]}{(RE2+R)}$ 32CCCI_a (Laternate)Content (alternate)33CVIChlorophyll Content (alternate)34AVIVegetation Index35PVRChlorophyll Vegetation Index36IRECIPhotosyntheti CV igour CV igour Ratio37ARVI2Inverted Red Edge Chlorophyll Index38mNDVIModified39NDVIMONTR CI30NDVI $\frac{(NNIR \times (1 - R)) \times (NNIR - R)}{RE1}$			Absorption	[(<i>RE</i> 1)]
Image: series of the series	26	TCARI	and	$3\left[(RE1-R) - 0.2(RE1-G)\left(\frac{RE1}{R}\right)\right]$
IndexIndex27PSRIPlant Sensecence Reflectance $\frac{R-B}{RE2}$ 28NPCINormalised Pigment Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 29MCARI _altModified Chlorophyll Absorption in Reflectance Index (alternate) $\frac{(NNIR - RE2)}{(RE1 - R) - 0.2 \times (RE1 - G) + (\frac{RE1}{R}))}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2 + R)}$ 31MCARI Reflectance IndexModified Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2 + R)}$ 31MCARI Reflectance IndexModified Chlorophyll Reflectance Index $\frac{((NNIR - RE1) - 0.2(NNIR - G))}{(RE2 + R)}$ 33CCCI_a ItCanopy Chlorophyll Chlorophyll Content (alternate) $\frac{(NNIR - RE2)}{(NNIR + RE2)}$ 33CVIContent Index $\frac{(NNIR - RE2)}{(NNIR + R)}$ 34AVIVegetation Index $\frac{NNIR \times \frac{R}{G^2}}{\frac{R}{G^2}}$ 35PVRPhotosyntheti Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{G+R}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{G+R}$ 37ARVI2Mrospherica Index 2 $-0.18 + 0.17(\frac{(NNIR - R)}{NNIR + R})$ 38mNDVIModified NDVI $\frac{(NNIR - R)}{NNIR - R + 2 \times CO}$			Reflectance	
27PSRIPlant Senescence Reflectance $\frac{R-B}{RE2}$ 28NPCINormalised Pigment (Chlorophyll ratio Index $\frac{R-Co}{R+Co}$ 29MCARI altModified Chlorophyll alt $\frac{Modified}{Reflectance}$ Index (alternate) $\frac{(RE1-R)-0.2 \times (RE1-G) \times (RE1)}{(RE1-R)-0.2 \times (RE1-G) \times (RE1)}$ 30MTCIMerris Terrestrial Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2 + R)}$ 31MCARI PACARIModified Chlorophyll Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ 31MCARI Reflectance IndexModified Chlorophyll Absorption in Reflectance Index $\frac{(NNIR - RE1) - 0.2(NNIR - G)}{(RE2 + R)}$ 32CCCL_a ItCanopy Chlorophyll Quiternate $\frac{(NNIR - RE2)}{(NNIR + RE2)}$ 33CVICanopy Vegetation Index $\frac{(NNIR - RE2)}{(NNIR + R)}$ 34AVIVegetation Index $\frac{NNIR \times R}{G^2}$ 35PVRPhotosyntheti c Vigour Ratio $\frac{\rho \times NNIR - \rho \times R}{G + R}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{P \times RE1}$ 37ARV12Ily Resistant Vegetation Index 2 $-0.18 + 0.17 (\frac{NNIR - R}{NNIR + R})$ 38mNDVIModified Vegetation Index 2 $(NNIR - R) \times CO$			Index	
27PSRISenescence Reflectance $\overline{RE2}$ 28NPCINormalised Pigment (Chlorophyll alt $\frac{R - Co}{R + Co}$ 29MCARI altAbsorption in Reflectance Index (alternate) $\frac{(RE1 - R) - 0.2 \times (RE1 - G) \times (RE1)}{(RE1 - G) \times (RE1)}$)30MTCIMerris Terrestrial Chlorophyll Index $\frac{((NNIR - RE2)}{(RE2 + R)}$)31MCARI PARIModified Chlorophyll Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ 31MCARI RE1Modified Chlorophyll Index $\frac{(NNIR - RE2)}{(RE2 + R)}$ 32CCCL_a ItConcent (alternate) $\frac{(NNIR - RE2)}{(NNIR - RE1)}$ 33CVIConcent Vegetation Index $\frac{(NNIR - RE2)}{(NNIR + RE2)}$ 34AVIVegetation Index $\frac{\sqrt{(NNIR - RE2)}}{(NNIR + R)}$ 35PVRPhotosyntheti c Vigour Ratio $\frac{G - R}{G + R}$ 36IRECIInverted Red Edge Chlorophyll Index $\frac{\rho \times NNIR - \rho \times R}{\rho \times RE1}$ 37ARV12Novin Modified Vegetation Index 2 $-0.18 + 0.17 (\frac{NNIR - R}{NNIR + R})$ 38mNDVINDVI $\overline{NDVIR - R + 2 \times CO}$			Plant	R - B
Reflectance $REL28NPCINormalisedPigmentChlorophyllatio Index\frac{R-Co}{R+Co}29MCARI_altAbsorption inReflectance(alternate)((RE1-R)-0.2 \times (RE1-G) \times (\frac{RE1}{R})))30MCARI_altAbsorption inReflectance(alternate)((RE1-R)-0.2 \times (RE1-G) \times (\frac{RE1}{R})))30MTCIMerrisTerrestrialChlorophyllIndex((RE1-R)-0.2 \times (RE1-G) \times (\frac{RE1}{R})))31MCARIMerrisTerrestrialChlorophyllIndex((RE1-R)-0.2 \times (RE1-G) \times (\frac{RE1}{R})))31MCARIMerrisTerrestrialChlorophyllIndex((RE2+R))32CCCL_aItChlorophyllChlorophyllIt((NNIR - RE2))(NNIR - RE1) - 0.2(NNIR - G)]RE133CVICanopyContent(alternate)((NNIR - RE2))(NNIR + RE2)(NNIR + R)33CVIChlorophyllVegetationIndex\sqrt{(NNIR - RE2)}(NNIR + R)34AVIVegetationIndex\sqrt{(NNIR + RE2)}(NNIR + R)35PVRPhotosynthetic VigourRatio\frac{G-R}{G+R}\frac{\rho \times NNIR - \rho \times R}{\rho \times RE1}36IRECIInverted RedEdgeChlorophyllIndex\frac{\rho \times NNIR - \rho \times R}{\rho \times RE1}37ARV12NoviriedNDVI-0.18 + 0.17 (\frac{NNIR - R}{NNIR + R})38mNDVIModifiedNDVI(NNIR - R + 2 \times CO)$	27	PSRI	Senescence	RF2
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36IRECIEdge Chlorophyll Index $\rho \times NNIR - \rho \times R$ $\frac{\rho \times RE2}{\rho \times RE1}$ 37ARVI2Atmospherica lly Resistant Vegetation Index 2 $-0.18 + 0.17 \left(\frac{NNIR - R}{NNIR + R}\right)$ 38mNDVIModified NDVI $(NNIR - R)$ $\overline{NNIR - R + 2 \times CO}$	36	IRECI	Inverted Red	
36IKECIChlorophyll $\frac{\rho \times RE2}{\rho \times RE1}$ IndexIndex $\frac{\rho \times RE2}{\rho \times RE1}$ 37ARVI2Atmospherica lly Resistant Vegetation Index 2 $-0.18 + 0.17 \left(\frac{NNIR - R}{NNIR + R}\right)$ 38mNDVIModified NDVI $(NNIR - R)$ $\overline{NNIR - R + 2 \times CO}$			Edge	$\rho \times NNIR - \rho \times R$
Index37ARVI2Atmospherica Ily Resistant Vegetation Index 2 $-0.18 + 0.17 \left(\frac{NNIR - R}{NNIR + R} \right)$ 38mNDVIModified NDVI $(NNIR - R)$ $\overline{NNIR - R + 2 \times CO}$			Chlorophyll	$\frac{\rho \times RE2}{\rho \times RE1}$
37ARV12Atmospherica Ily Resistant Vegetation Index 2 $-0.18 + 0.17 \left(\frac{NNIR - R}{NNIR + R}\right)$ 38mNDVIModified NDVI $(NNIR - R)$ $\overline{NNIR - R + 2 \times CO}$			Index	
37ARVI2IIy Kesistant Vegetation Index 2 $-0.18 + 0.17 \left(\frac{NNIR - R}{NNIR + R}\right)$ 38mNDVIModified NDVI $(NNIR - R)$ $\overline{NNIR - R + 2 \times CO}$	37	ARVI2	Atmospherica	
VegetationIndex 238mNDVIModified $(NNIR - R)$ NDVI $\overline{NNIR - R + 2 \times CO}$			Ily Resistant	$-0.18 + 0.17 \left(\frac{NNIR - R}{NNIR + R} \right)$
$\begin{array}{c c} \text{38} & \text{mNDVI} & \text{Modified} \\ \text{NDVI} & \text{NDVI} & \frac{(NNIR - R)}{NNIR - R + 2 \times CO} \end{array}$			Index 2	(WWINTK + K)
38 mNDVI NDVI $\frac{(mnn + 1)}{NNIR - R + 2 \times CO}$			Modified	(NNIR - R)
	38	mNDVI	NDVI	$\overline{NNIR - R + 2 \times CO}$

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No	Indices	Full name	Formula Based on S2 bands
39	MNDR E	Modified Normalised Difference Red-edge	$\frac{(RE2 - RE1)}{RE2 - RE1 + 2 \times CO}$
40	MACC	Maccioni	$\frac{(RE3 - RE1)}{RE3 + R}$
41	Datt	Datt	$\frac{(NNIR - RE1)}{(NNIR + R)}$
42	NDVI2	NDVI2	$\frac{(RE2 - RE1)}{(RE2 + RE1)}$
43	NDVI3	NDVI3	$\frac{(R-G)}{(R+G)}$
44	MTCI_ at	Meris Terrestrial Chlorophyll Index	$\frac{(RE2 - RE1)}{RE1 - R}$
45	BUI	Built-up Index	$\left(\frac{S1 - NNIR}{S1 + NNIR}\right) - \left(\frac{NNIR - R}{NNIR + R}\right)$
46	NDWI_ G_N	Normalised Difference Water Index (using G and N bands)	$\frac{G - NNIR}{G + NNIR}$
47	NMDI	Normalised Multiband Drought Index	$\frac{(NNIR - (S1 - S2))}{(NNIR + (S1 - S2))}$
48	NDRE	Normalised Difference Red Edge	$\frac{NNIR - RE1}{NNIR + RE1}$
49	CCCI	Canopy Content Chlorophyll Index	$\frac{(NNIR - RE2)/(NNIR + RE2)}{(NNIR - R)/(NNIR + R)}$
50	SELI	Sentinel Estimated Leaf-Area Index	NNIR – RE1 NNIR + RE1
51	LAI_alt	Leaf-Area Index (alternate)	SELI*5.405-0.114
52	DM_N DVI	Dry Mass using NDVI	NDVI*12.3245-5.70

Table 4. Index description