Utilizing Normalised Difference Red Edge Index to predict Nitrogen content in Fodder crops from Hyperspectral and Multispectral Data.

Report submitted for completion of training

Submitted by
NISHANT
Int MSc. (Mathematics)

Under the guidance of

Dr Sujay Dutta
SCI/ENG – SG
EPSA
Space Applications Centre, (ISRO) Ahmedabad

Institution
Sardar Vallabhbhai National Institute of Technology
Surat – 395007
Gujarat

SRTD-RTCG-MISA
Space Applications Centre (ISRO)
Ahmedabad, Gujarat

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Abstract

Hyperspectral reflectance data from 350 nm to 2500 nm is used to assess Lab nutritive data for Fodder crops which includes samples of Berseem and Maize. With the help of Hyperspectral data, we find the particular wavelength where all fodder crops' spectral absorption have maximum correlation with the Nitrogen content in the plants. To establish correlation we quantify the spectral absorption using the Band depth at each wavelength. We show through our results that Band Depth at 676 nm has the highest correlation with Nitrogen content in plants. We then devise a method to use Multispectral satellite imagery to predict Nitrogen content using Normalised difference Red Edge Index (NDRE) derived from Red Edge Band as it contains 676 nm wavelength where hyperspectral data confirmed high correlation with nitrogen. The NDRE values also show above 87 % correlation with Nitrogen data. We train a linear regression machine learning model to predict Nitrogen content using NDRE index value. We obtain an accuracy over 75 percent. We then classify all the crops into Good, Moderate and Low in Nitrogen content in the study area of a farm in NDRI Karnal therefore eliminating the time consuming lab analysis and saving resources.

1. Introduction

Nutrients in plants are mostly analyzed through the lab which is costly and require greater durations and efforts whereas with use of spectral graphs and study of absorption features at certain wavelength we can get a better understanding about plants health as well as to a great extent predict the nutrients in the plants **[1].** This fastens the process as well as reduces need for resources and time. The crops such as Berseem and maize grouped as Fodder crops are analyzed to find how spectral graphs can help in correlating Nitrogen content in plants and spectral absorptions. In order to quantify and utilize absorption for correlation we measure the band depth at the particular wavelength. Band depth calculation is done using continuum removal **[2]**. For each wavelength the reflectance values and corresponding reflectance value after the continuum line is used to obtain the band depth. The exact process is detailed in section 3.1. Now the more positive the value of Band Depth is the higher absorption it shows. Another index helpful for prediction of Nitrogen is the Normalised Difference Red Edge index calculated using Near Infrared Band and Red Edge. The Normalized Difference Red Edge Index (NDRE) is a vegetation index commonly used in remote sensing and precision agriculture to assess vegetation health and properties **[3]**. It is particularly sensitive to changes in chlorophyll content and leaf structure, providing valuable information about plant vigor, stress, and nutrient levels. The formula used is $NDRE = \frac{NIR-RE}{NIR+RE}$

where NIR is a Near Infrared band and RE is the Red Edge band.

2. Data and Sources

The study area is in the farm of NDRI Karnal from where Hyperspectral, Multispectral and Lab data is collected. Complete region consists of 97 plots each with a specific sample of crop. Out of 97 plots, 9 plots are labeled with types and samples of crops in them and Lab Nitrogen data. They are mentioned in Table 1 and Figure 1. From each plot a plant sample is taken and hyperspectral data from Band 300 to Band 2500 is captured using handheld spectroradiometer. Along with this the selected plants are also analyzed in the lab for nitrogen and the data is recorded. The Multispectral data is obtained from PlanetScope 2482, LEO-SSO with

3 meter resolution. on 2023-02-07 in GeoTIFF format. Latitude and Longitude of the multispectral image is

The topLeft - 29.7845, 76.7826

The topRight - 29.7812, 76.7823

The bottomLeft - 29.5336, 76.7896

The bottomRight - 229.5369, 77.1856

Table 1 - Lab results of Nitrogen content in samples taken from specific plots.

Crops	Lab - N%	Plot
Berseem1	2.66	13
Berseem2	2.52	11
Berseem3	2.604	9
Berseem4	2.548	18
Maize2	1.512	31
Maize3	1.484	34
Maize4	1.372	32
Maize5	1.4	33
Maize6	1.484	28

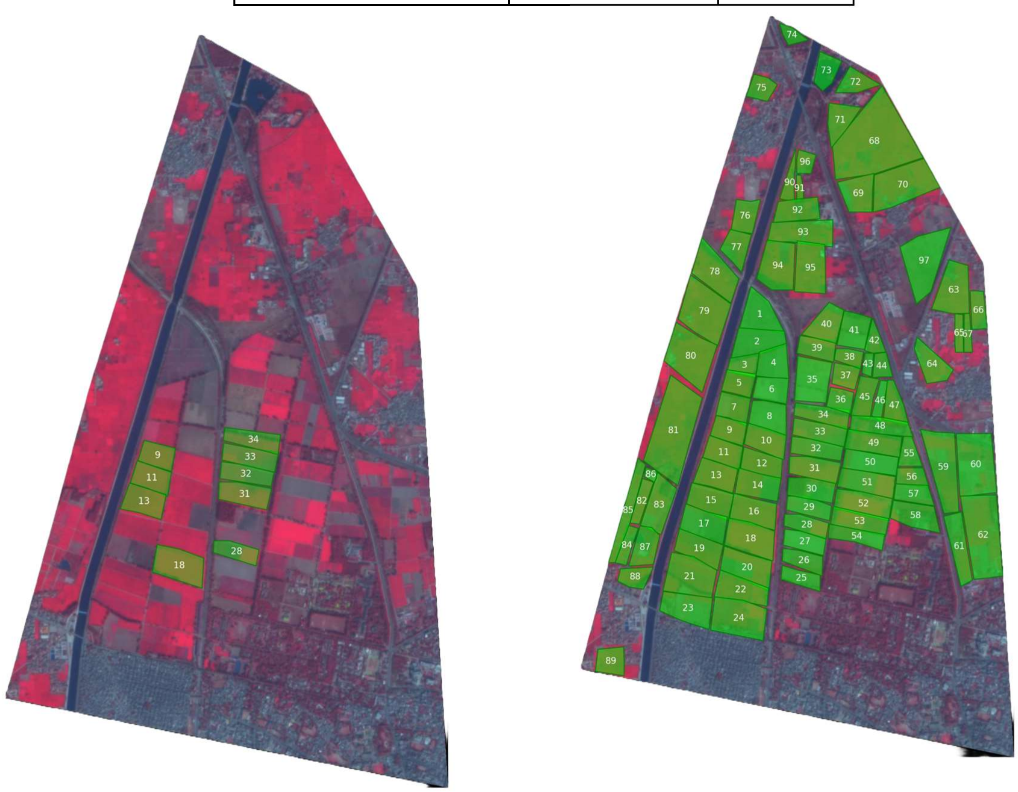


Fig 1 - False Colored Composite using (`Near-Infrared (0.865), Red (0.665), Green (0.565)` **) of the Multispectral image with plots from where lab samples taken are highlighted and the second subplot shows all 97 identified plots.**

Table 2 - Hyperspectral data from Handheld spectroradiometer for each crops with their Plot Number

Crops	Lab - N%	Plot	350	351	352	353	…	2498	2499	2500
Berseem1	2.66	13	0.02131	0.02128	0.02124	0.02119	…	0.4787	0.39348	0.28914
Berseem2	2.52	11	0.0165	0.01641	0.01632	0.01621	…	0.34522	0.32932	0.32446
Berseem3	2.604	9	0.0136	0.01355	0.01349	0.01344	…	0.08579	0.1168	0.13778
Berseem4	2.548	18	0.02055	0.02053	0.02051	0.02047	…	0.2967	0.35724	0.40251
Maize2	1.512	31	0.01795	0.01788	0.01782	0.01774	…	0.52162	0.59846	0.67037
Maize3	1.484	34	0.07379	0.07382	0.07389	0.07396	…	0.50332	0.33375	0.20938
Maize4	1.372	32	0.04574	0.04572	0.04568	0.04561	…	0.39931	0.3999	0.44203
Maize5	1.4	33	0.03688	0.03684	0.03679	0.03672	…	0.20091	0.17226	0.13888
Maize6	1.484	28	0.02012	0.0201	0.02008	0.02004	…	0.16817	0.13977	0.12494

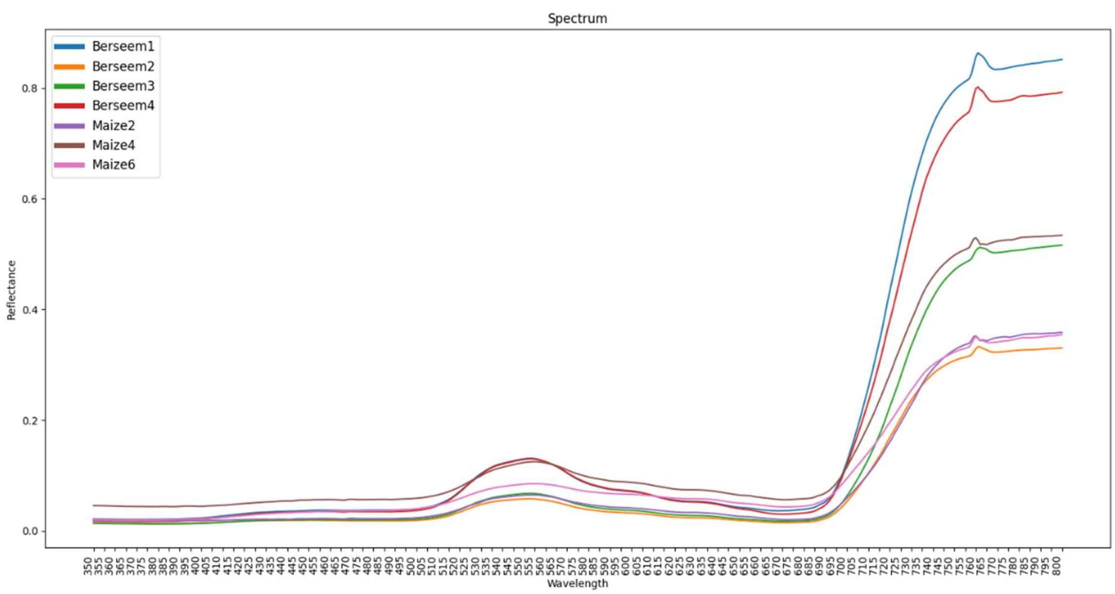


Fig 2 - Spectrum from Hyperspectral data 500 to 800 nm

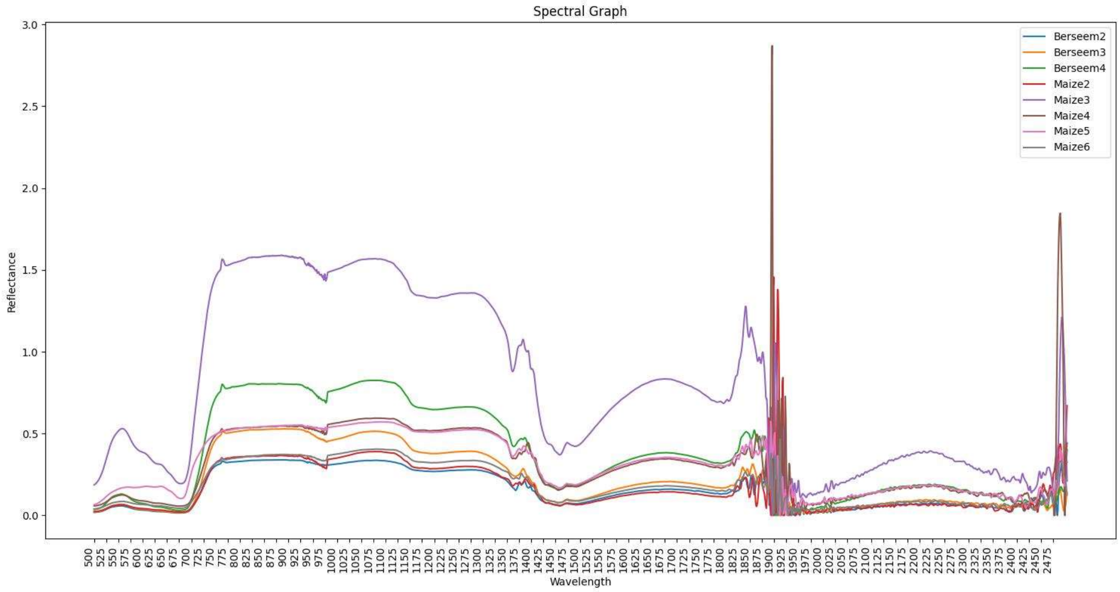


Fig 3 - Spectrum from Hyperspectral data 500 to 2500 nm

3. Method and Analysis

The objective is to show that wavelengths in the Red Edge region have the absorption feature with highest correlation with the Lab Nitrogen data. For this we obtain band depth at each nm in the Red edge region through continuum removal. The complete process is described in section 3.1. We Then prepare a Linear regression model to predict nitrogen for all plots in the multispectral image and classify them into High, low and decent nitrogen content. The model is trained to use the Normalised Difference Red Edge index to predict Nitrogen. The process of obtaining NDRE is detailed in section 3.2. We use the model to predict Nitrogen content for all the identified plots in the multispectral image. Using the predicted nitrogen percentage of all the crops we classify each of the plots into High, low and decent nitrogen content.

Following flowchart describes the methodology used

Wavelength in range (550 , 760)
↓
Band Depth Calculated

↓

Wavelength with highest correlation identified
(Band Depth and Nitrogen)

↓

Correlation of Red Edge band with Nitrogen validated

↓

NDRE for each plots in Multispectral calculated

↓

Linear regression Model Trained

↓

Prediction for all plot in Multispectral image

↓

All plots Classified into Good, Moderate and Low in N%

Fig 3 - Methodology Flowchart

3.1 Band depth calculation using Continuum Removal for wavelength in range 550 to 760 (Red Edge) from hyperspectral data for all 9 crops

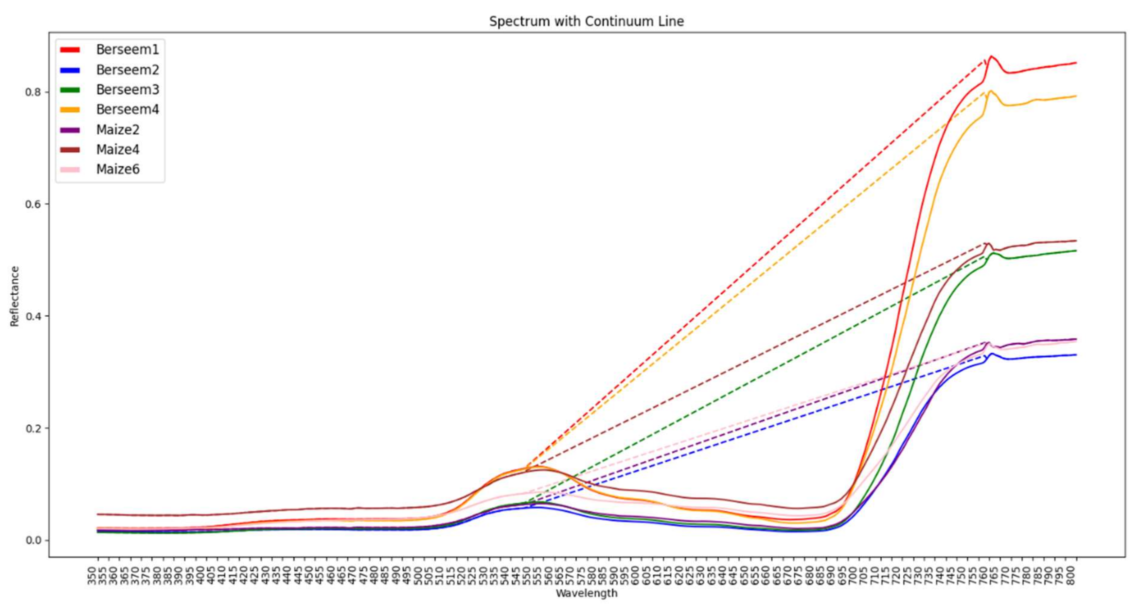
The band depth is measured using continuum removal technique. The continuum line start for the Red edge region lies in the position of maximum reflectance after the former absorption i. e at 550 nm, and the continuum line end lies in the position of maximum reflectance before the later absorption i.e around 760 nm. The formula for Band depth is 1 minus the ratio of actual value on the spectral graph and value on the continuum removed line at a wavelength is the band depth at that wavelength **[2]** . The formula is denoted as Band Depth = 1 - ((Original Reflectance Value at the specific Wavelength) / (Reflectance Value on Continuum Line at that Wavelength)).

$$BD = 1 - \left(\frac{R_{\text{original}}(\lambda)}{R_{\text{continuum}}(\lambda)} \right)$$

Where:

- BD is the band depth.
- $R_{\text{original}}(\lambda)$ is the original reflectance value at the specific wavelength λ.
- $R_{\text{continuum}}(\lambda)$ is the reflectance value on the continuum line at that wavelength λ.

For example if Band depth at wavelength 700 nm needs to be calculated then a continuum line is made from position of maximum reflectance after the former absorption i. e at 550 nm, and the continuum line end lies in the position of maximum reflectance before the later absorption i.e around 760 nm FOr visualisation refer to Fig 1. Then the value at 700 nm on the spectral graph is divided by the value of 700 nm on the continuum line. This value obtained is the continuum removed value at 700 nm. To obtain the band depth, the continuum removed value at 700 nm is subtracted from 1



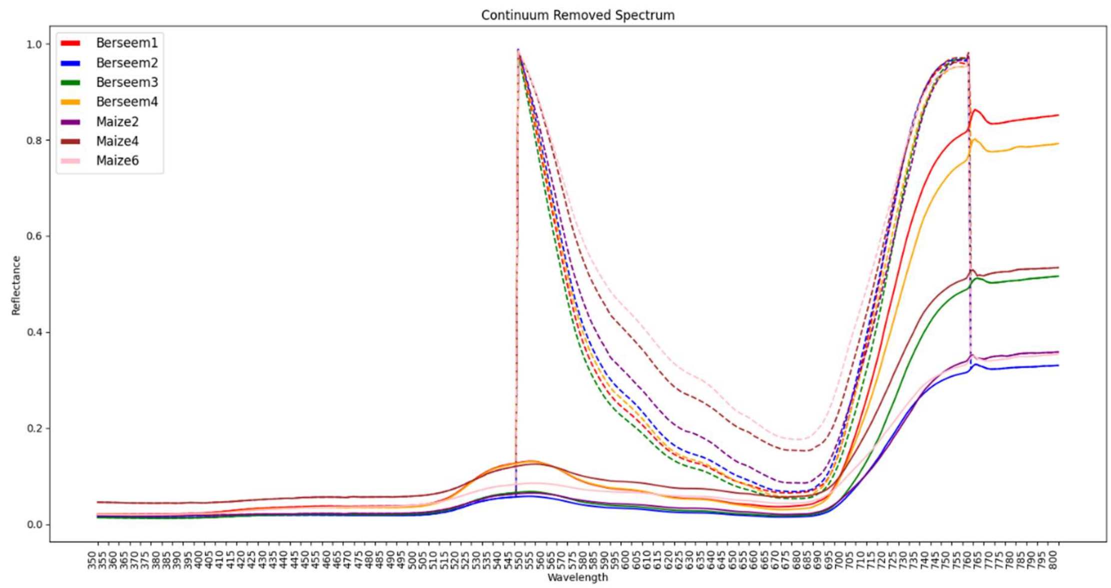


Fig 1 - Band Depth calculation for wavelength in Red Edge Region from 550 to 760 nm by continuum removal.

Table 3 - All calculated Band Depths from Hyperspectral data

	550	551	552	553	554	555	556	557	558	559	...	751	752	753	754	755	756	757	758	759	760
0	0.074	0.093	0.112	0.131	0.151	0.172	0.194	0.216	0.239	0.262	...	0.039	0.039	0.039	0.04	0.04	0.042	0.042	0.036	0.0	0.0
1	0.062	0.0800	0.097	0.115	0.133	0.154	0.175	0.195	0.216	0.237	...	0.034	0.034	0.034	0.034	0.03	0.036	0.036	0.032	0.0	0.0
2	0.085	0.107	0.129	0.151	0.173	0.197	0.221	0.245	0.269	0.292	...	0.035	0.033	0.032	0.032	0.03	0.031	0.031	0.028	0.0	0.0
3	0.069	0.086	0.103	0.122	0.141	0.161	0.181	0.203	0.225	0.247	...	0.050	0.049	0.040	0.048	0.04	0.049	0.047	0.038	0.0	0.0
4	0.060	0.074	0.0910	0.107	0.123	0.139	0.155	0.173	0.193	0.213	...	0.039	0.037	0.036	0.034	0.03	0.034	0.032	0.023	0.0	0.0
5	0.045	0.054	0.0650	0.076	0.088	0.100	0.113	0.127	0.141	0.157	...	0.030	0.030	0.029	0.029	0.02	0.030	0.029	0.018	0.0	0.0
6	0.043	0.053	0.063	0.074	0.086	0.098	0.110	0.123	0.137	0.150	...	0.050	0.049	0.049	0.049	0.04	0.049	0.047	0.033	0.0	0.0
Average	0.062	0.078	0.0946	0.110	0.127	0.145	0.164	0.183	0.202	0.222	...	0.039	0.038	0.038	0.038	0.03	0.038	0.037	0.029	0.0	0.0
Total	0.5001	0.625	0.754	0.88	1.022	1.166	1.313	1.465	1.622	1.780	...	0.316	0.309	0.305	0.304	0.3	0.309	0.301	0.237	0.0	0.0

The average band depth of all 9 crops is calculated for each wavelength and wavelength with highest average are sorted. Among these wavelengths which have highest band depths the correlation is calculated with Lab Nitrogen data of the 9 crop samples and the wavelength with highest correlation is picked. We get wavelength 676 with high absorption feature as well as the highest correlation with nitrogen lab data.

Table 4 - Wavelength with highest correlation from Hyperspectral data. 676 nm has the highest correlation.

	Crops	Lab - N%	678	679	677	674	675	676	673	680	681	672
0	Berseem1	2.660	0.934	0.934	0.934	0.935	0.93	0.93	0.93	0.934	0.933	0.935
1	Berseem2	2.520	0.932	0.932	0.932	0.93	0.932	0.93	0.93	0.931	0.931	0.932
2	Berseem3	2.604	0.947	0.947	0.947	0.947	0.947	0.947	0.94	0.946	0.946	0.946
3	Berseem4	2.548	0.942	0.942	0.942	0.94	0.942	0.942	0.942	0.941	0.941	0.942
4	Maize2	1.512	0.914	0.914	0.91	0.914	0.914	0.914	0.914	0.914	0.914	0.914
5	Maize4	1.372	0.84	0.847	0.846	0.84	0.846	0.846	0.846	0.847	0.847	0.845
6	Maize6	1.484	0.824	0.824	0.824	0.82	0.823	0.82	0.822	0.823	0.823	0.821
Average	NaN	NaN	0.905	0.905	0.905	0.90	0.905	0.90	0.905	0.90	0.905	0.905
Total	NaN	NaN	7.244	7.245	7.24	7.24	7.244	7.24	7.242	7.24	7.240	7.240
Correlation	NaN	NaN	0.845	0.84	0.846	0.846	0.8467	0.8467	0.845	0.84	0.8418	0.844

3.2 Calculating Normalised Difference Red Edge Index for all plots in Multispectral

The Normalized Difference Red Edge Index (NDRE) is a vegetation index commonly used in remote sensing and precision agriculture to assess vegetation health and properties **[3]**. It is particularly sensitive to changes in chlorophyll content and leaf structure, providing valuable information about plant vigor, stress, and nutrient levels **[4]**. The formula used is

$$NDRE = \frac{NIR-RE}{NIR+RE}$$

To obtain the NDRE index of each plot, 50 sample points from each plot are selected and the NDRE value calculated using the mentioned formula i.e fc $NDRE = \frac{NIR-RE}{NIR+RE}$ use the formula, first the radiance value is obtained by reading pixel value from Multispectral NIR and Red edge band. From the metadata, these radiance values are converted to reflectance by multiplying with the respective reflectance factor. Once the NDRE index is obtained for all crops from multispectral data we train a linear regression model to predict Nitrogen in plants.

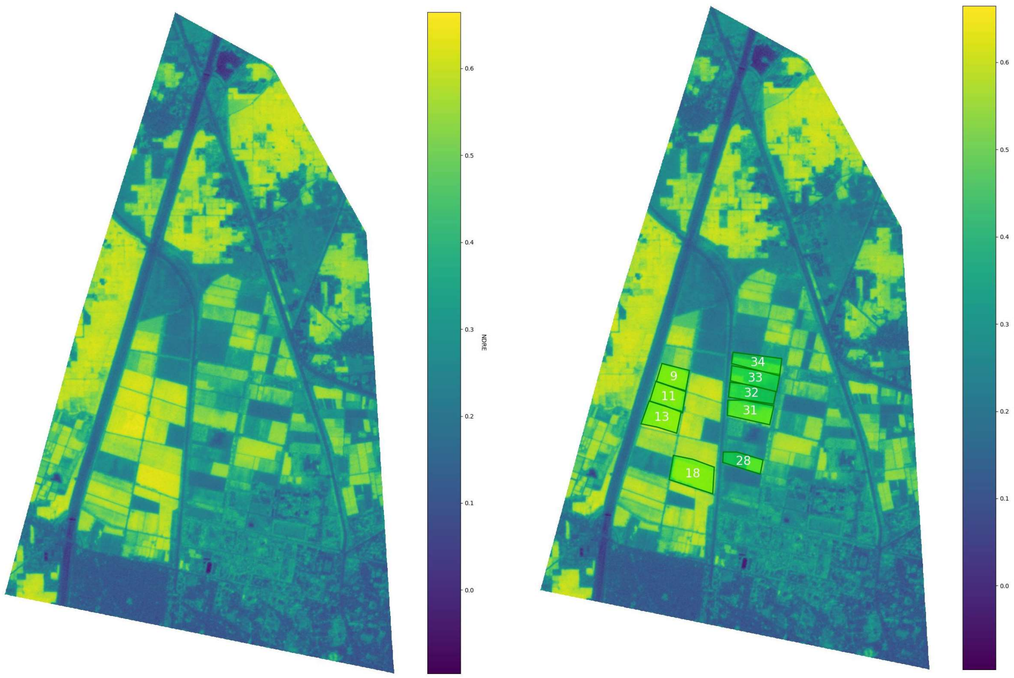


Fig 5 - NDRE Plot of Multispectral image. Second image shows the plots with Lab data

Table 5 - Average Band depth for each plot with lab data from Multispectral data by selecting 10 points from each plot

Crops	Lab - N%	Plot	Average NDRE for the plot from Multispectral at Red Edge Band
Berseem1	2.66	13	0.619408
Berseem2	2.52	11	0.535441
Berseem3	2.604	9	0.624234
Berseem4	2.548	18	0.647772
Maize2	1.512	31	0.518660
Maize3	1.484	34	0.342860
Maize4	1.372	32	0.310731
Maize5	1.4	33	0.406358
Maize6	1.484	28	0.307777
		Correlation of N% with NDRE	0.8717

3.4 Training Linear Regression model using NDRE all crops with lab data to predict Nitrogen content

The linear regression model is trained using NDRE values of each plot as Input column and Nitrogen percentage data as Target column. The total data consist of 9 crop samples which are all used for training of the model. The prediction on the whole dataset produces 0.28 Root mean square

Error and R2 score of 0.76. The model is trained on the crop’s NDRE and lab nitrogen data.

Linear regression is a statistical method used to model the relationship between a dependent variable and one or more independent variables by fitting a linear equation to observed data. It aims to find the best-fitting straight line through the data points. This line can then be used to predict the value of the dependent variable based on the values of the independent variables. The equation of a simple linear regression model is typically represented as:

$$Y = \beta_0 + \beta_1 X + \varepsilon$$

Where Y is the dependent variable.
X is the independent variable. Beta 0 is the intercept and Beta 1 is the slope.

Here in our data Y = Nitrogen %, and X is NDRE values.
The final linear regression equation with weights is

Nitrogen % = NDRE * 3.75 + 0.14875
where 3.75 is the weight and 0.14875 is the intercept

Table 6 - Input and Target column in Linear regression Model

	Crops	Plot	Training Data - NDRE per Plot	Target - Actual N%	Predicted N%
0	Berseem1	13	0.619408	2.660	2.479333
1	Berseem3	9	0.535441	2.604	2.164481
2	Berseem4	18	0.624234	2.548	2.497427
3	Berseem2	11	0.647772	2.520	2.585687
4	Maize2	31	0.518660	1.512	2.101556
5	Maize6	28	0.342860	1.484	1.442362
6	Maize3	34	0.310731	1.484	1.321886
7	Maize5	33	0.406358	1.400	1.680458
8	Maize4	32	0.307777	1.372	1.310810

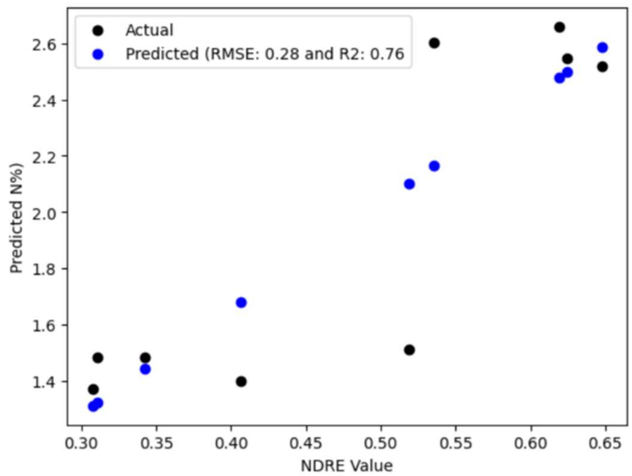


Fig 7 - Model Prediction scatter plot

Model is used to predict N% for all plots after calculating NDRE for each plot. The results are shown in Table 7.

Table - 7 - Band Depth for all 97 identified plots

	Plot_Number	NDRE	N%_Predicted
0	1	0.159859	0.756163
1	2	0.237401	1.046922
2	3	0.449787	1.843306
3	4	0.222059	0.989395
4	5	0.463789	1.895810
...	...	...	...
92	93	0.571333	2.299064
93	94	0.396092	1.641964
94	95	0.502006	2.039112
95	96	0.371984	1.551569
96	97	0.244484	1.073482

3.6 Classifying Plots on Basis of predicted Nitrogen content

Using the plots with lab data we devise a custom classification method where N% > 2% is termed Good, 1.45% < N% <= 2% termed as Moderate and N% < 1.45% classified as Low in Nitrogen content. This is done to get a basic analysis of all crops in the multispectral image. So plots with predicted N% are compared using the custom classification rule. The result is attached in Fig 8. Plots with good nitrogen content are coloured green, plots with Moderate Nitrogen coloured Yellow and Plots with low Nitrogen are colored Orange.

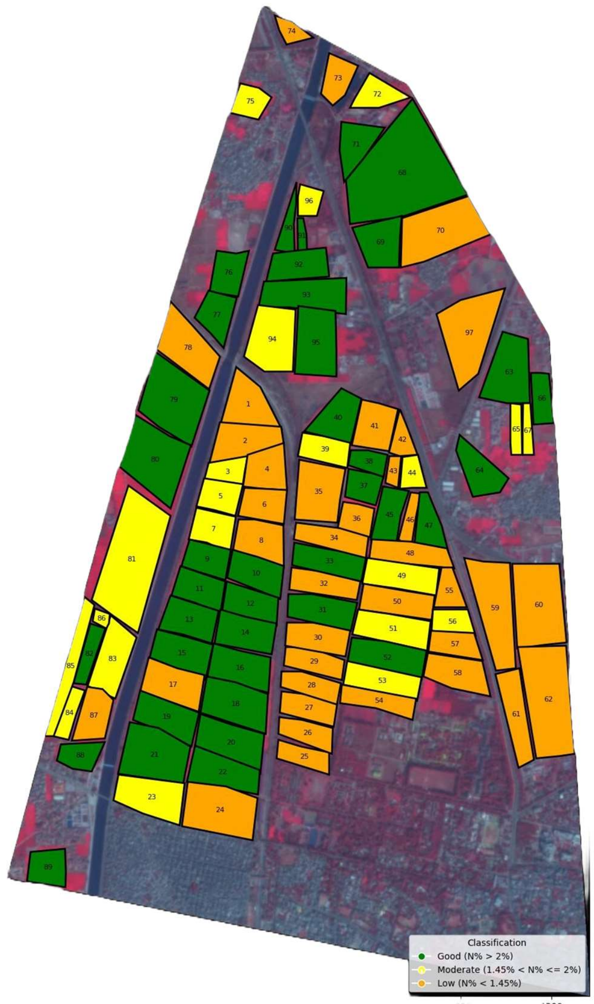


Fig 8 - All 97 plots classified on basis of predicted Nitrogen percentage represented on FCC

[Good (N% > 2%) Moderate (1.45% < N% <= 2%) Low (N% < 1.45%)]

4. Conclusion

In conclusion, this study demonstrates the potential of hyperspectral and multispectral remote sensing in assessing the nitrogen content of fodder crops, Berseem and Maize. By analyzing hyperspectral reflectance data, we identified a specific wavelength, 676 nm, which shows the highest correlation with nitrogen content across various crops.

Utilizing this finding, we devised a method to predict nitrogen content using multispectral satellite imagery, by using the Normalized Difference Red Edge Index (NDRE) derived from the Red Edge Band. The results showed a strong correlation of over 87% between NDRE values and actual nitrogen content, indicating the efficacy of this approach.

Furthermore, through the application of a linear regression machine learning model, we were able to accurately predict nitrogen content using NDRE index values, achieving an accuracy exceeding 75%.

By classifying crops into categories of nitrogen content (Good, Moderate, and Low) within the study area of a farm in NDRI Karnal, we provide insights for agricultural management.

Overall, the study highlights the application of remote sensing with machine learning algorithms in helping agricultural practices by providing timely and cost-effective solutions for nutrient assessment and crop management.

Reference

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भारत सरकार
अंतरिक्ष विभाग
अंतरिक्ष उपयोग केन्द्र
आंबावाडी विस्तार डाक घर,
अहमदाबाद-380 015. (भारत)
दूरभाष : +91-79-26913050, 26913060
वेबसाईट : www.sac.isro.gov.in/www.sac.gov.in

Government of India
Department of Space
SPACE APPLICATIONS CENTRE
Ambawadi Vistar P.O.
Ahmedabad - 380 015. (INDIA)
Telephone : +91-79-26913050, 26913060
website : www.sac.isro.gov.in/www.sac.gov.in

वैज्ञानिक अनुसंधान एवं प्रशिक्षण प्रभाग (एसआरटीडी)

Scientific Research and Training Division (SRTD)

आरटीएमजी/मीसा/सैक RTMG/MISA/SAC

CERTIFICATE

this is to certify that **Mr. Nishant**, a student of integrated MSc (Mathematics) of Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat has completed a four months (15 December-2023 to 26 April-2024) project on **"Utilizing Normalised Difference Red Edge Index To Predict Nitrogen Content In Fodder Crops from Hyperspectral And Multispectral Data"** under the supervision of Dr. Sujay Dutta, Head, Sci/Engr-SG, EPSA-AESG-PACD, Space Applications Centre (ISRO), Ahmedabad. The research work was carried out through Scientific Research and Training Division (SRTD) Of Space Applications Centre, Ahmedabad.

डॉ सर्वेश्वर व्यास / Dr. S.P. Vyas
प्रधान, वैज्ञानिक अनुसन्धान एवं प्रशिक्षण प्रभाग
Head, Scientific Research and Training Division
एसआरटीडी-आरटीएमजी मीसा / SRTD-RTMG-MISA
अंतरिक्ष उपयोग केंद्र (इसरो)
Space Applications Centre (ISRO)
अंतरिक्ष विभाग/Department of Space
भारत सरकार/Govt. of India
अहमदाबाद/Ahmedabad - 380015.