# EFFECTIVENESS OF SPECTRAL SIMILARITY MEASURES TO MONITOR HEALTH OF CROPS FOR SUSTAINABLE AGRICULTURE

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## ABSTRACT

*This research paper attempts to show efficient use of spectral similarity measures to check desired growth of the crops by comparing farmer's field crops spectra with test field crops spectra of same development stage. Optimum amount of nitrogen (as fertiliser) and water applied increase the NIR reflectance. Dissimilarity in vegetation vigour, resulting from variation in nitrogen and water applied, are easily located when NIR imagery or data are used. Stress is shown by progressive decrease in NIR reflectance. The study is carried out for three different crops and field spectra collected from farmers' field were compared with test fields at IARI, New Delhi. Spectral Information Divergence is used as spectral similarity measure and close match between farmer's and test field spectra has been found for four levels of nitrogen and water applied to chickpea, sorghum and wheat crops. Similarity of spectra from farmer's fields with test fields is mapped by SID measure equivalent to co-efficient of correlation and average SID measure equivalent to co-efficient of correlation for chickpea was 0.997, for sorghum was 0.996 and for wheat was 0.994. SID similarity among spectra from farmer's fields with spectra from test fields, if crops were water stressed: 0.997 for chickpea, 0.996 for sorghum and 0.991 for wheat. SID similarity among spectra of farmer's and test fields, if crops were Nitrogen stressed: 0.997 for chickpea, 0.994 for sorghum and 0.997 for wheat.*

**Keywords:** Spectral Similarity Measure, Spectral Information Measure, Spectral Information Divergence, Regulated Field and Unregulated Field.

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## Introduction

Spectral reflectance curves provide insight details of the spectral characteristics of an object (Lillesand and Kiefer, 1999). Contiguous spectral signatures are obtained from field spectrometers. Detailed analysis for the detection of surface materials and their abundances, as well as inferences of biological and chemical processes is possible due to contiguous spectral signatures.

Efficient use of Spectral Similarity Measures (SSMs) was shown to discriminate amongst vegetation and surroundings soil by Chang (2000) and Du et. al, (2004), to discriminate among mineral spectra by Van der Meer, (2005), to classify crop types by Kong et.al, (2010) and to build up precise field crop spectra based on collected field spectra by Chauhan and B. Krishna Mohan, (2014).

It is very essential to monitor the actual growth of the crops. The major two factors which govern the growth of the crops were timely and appropriate application of nitrogen (as fertiliser) and water. To monitor the crop growth collection of data for nitrogen and water applied from actual field is quite cumbersome or very difficult. Filella and Penuelas (1994) studied the effect of optimum and deficit nitrogen and water applied to various crops and carried out shape analysis of spectra due to variation in nitrogen and water applied. Major four groups: HNHW, HNLW, LNHW and LNLW (where, H-High, L-Low, N-Nitrogen, W-Water) were formed to study the problem of deficiency in nitrogen and water applied.

Field spectra for chickpea, sorghum and wheat were collected from the study area. Field spectra also collected from the regulated field condition of variation in nitrogen and water applied at test field plots of Indian Agriculture Research Institute (IARI), New Delhi for chickpea, sorghum and wheat. A study has been carried out to check spectral similarity of the spectra collected in the regulated field conditions with the spectra collected from unregulated (study area) field conditions. A good match among the spectra leads to use of matched spectra for the classification of the remote sensing image for the condition of the crop. It makes monitoring of the crops a manageable task as data collection for nitrogen and water applied for variety of the crops is quite cumbersome and time consuming for real field study areas. To carry out the spectral similarity between field spectra of regulated site condition (at IARI) to unregulated site conditions (study area), Spectral Information Measure (SIM) based Spectral Information Divergence (SID) is used as similarity measure. Two pixel spectra are similar or not are checked by SID as computing the difference between their matching spectral signature-derived probability distribution of two pixels vectors.

Chang (2000) have proposed SID which is an information-theoretic approach to analyse spectral variability, similarity and discrimination. Chang (2000) tested and verified that the SIM-based criteria attained more effectively than the traditional Spectral Angle Measure (SAM). Van der Meer (2005) has used SAM, Euclidean Distance (ED) measure, Spectral Correlation Measure (SCM) and SID measure in distinguishing mineral

spectra among a known reference and unknown target spectrum and concluded that SID is more efficient in identifying the four target minerals. Kong *et al.* (2010) have used SCM, SAM, ED and SID measures in discriminating crop varieties. The experiment results showed that the SID and SCM can better discriminate two spectra and have better chance to identify a target spectrum via the known spectral library. Chauhan H.J., (2017, p. 56) have used City Block Distance (CBD), SAM and SID to differentiate among chickpea, sorghum and wheat and found that SID performs better than other two measures.

**Study Area and Field Data Collected**

Location of study area is at 20° N latitude and 76.5 ° E longitudes in Lonar and Mehekar villages of Buldhana district, Maharashtra, India. The climate of the study area is tropical semi arid and soil is alluvial. Irrigated areas have crops in *Rabi* season (October–February). Main crops during *Rabi* season are chickpea, sorghum and wheat and small crops are seasonal vegetables, and fruits. During field visit field spectra are collected from the plots in which time gap in sowing of the crops was not more than one week. Also average age of the crops was 60 days. As local weather conditions are same; timely and appropriate (quantity) application of nitrogen (as fertiliser) and water affect the growth of the crops. Plots are selected in such a way that visually infections in the crops were not observed. Hence, if crops are stressed, it is mostly due to inappropriate application of nitrogen (as fertiliser) and water.

Field observations were carried out for major three crops chickpea, sorghum and wheat. The instrument used to collect field spectra is GER 1500 spectroradiometer, also GPS locations were taken with handheld GPS receiver covering all major crop types. Field spectra were collected from 106 locations along with GPS locations. Wavelength range of 325 to 1075 nm was covered by a spectroradiometer with 512 channels. The readings were taken around solar before noon local time on cloud free days. Field spectra were collected carefully by taking all precautions as per standard procedure. Spectral library for specific crop was built form the collected spectra (Rao et. al., 2007, Gomez, R.B. 2001). Precision of the spectra was checked and outlier were rejected to build trustworthy spectral library (Chauhan and B. Krishna Mohan, 2014).
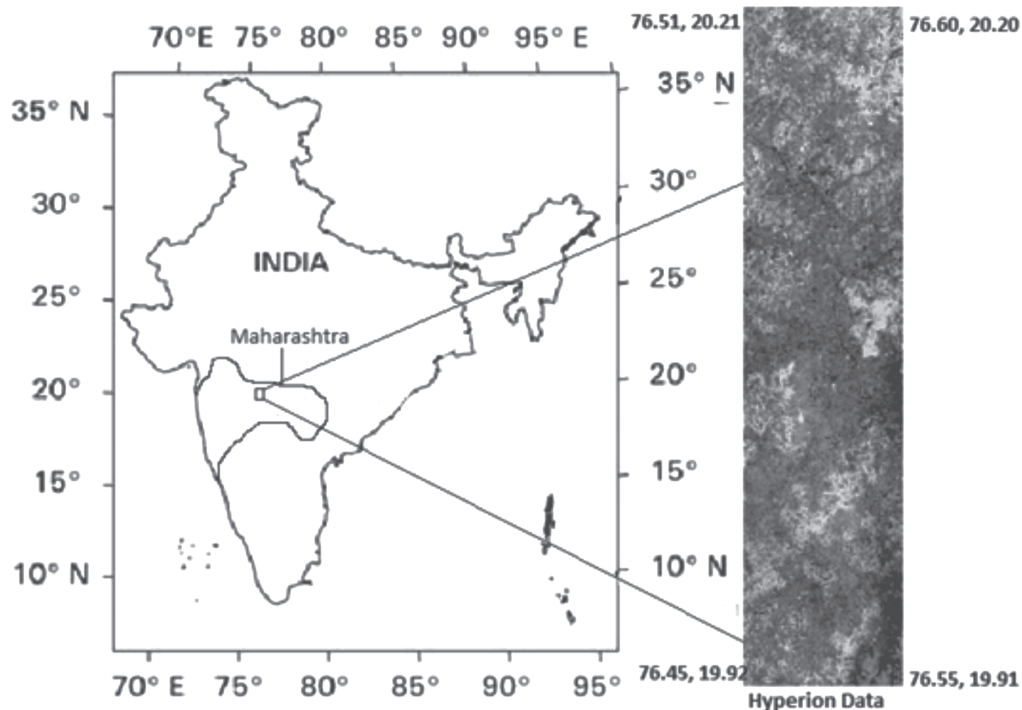
**Figure 1: Location of Study Area and Hyperspectral Data**

Field data of the chickpea, sorghum and wheat crops for controlled field conditions were also collected at the test sites at the average age of 60 days of Indian Agriculture Research Institute (IARI), New Delhi. These crops in the test bed were regulated for nitrogen and water. Optimum (100%) and 50 % of optimum nitrogen and water were applied to crops. Optimum was termed as high and 50 % of optimum was termed as low and four groups of spectra HNHW, HNLW, LNHW and LNLW were formed.

**Methodology**

A methodology is proposed to categorise field spectra of unregulated field plots as HNHW, HNLW, LNHW or LNLW. Spectral similarity analysis is carried out between field spectra of regulated and unregulated field plots. To carry out spectral similarity analysis, spectral information based spectra information divergence is used as spectral similarity measure. Labels as HNHW, HNLW, LNHW or LNLW were assigned to chickpea, sorghum and wheat crops classes based on closest spectral similarity.

SID (Chang, 2000 and 2003) is an innovative criterion to measure spectral resemblance, the base concept in SID is difference in spectral information (Kullback, 1997). SID measures the difference of probability between the spectral signatures of two pixel vectors. SID measures discrepancy among two pixel vector's corresponding spectral signature-derived probability distribution to check spectral

similarity among two pixels vectors. SID measures the distance among the probability distributions formed by the spectral signatures of two pixel vectors.

Two probability vectors p = $(p_1, p_2..........p_L)^T$ and $q = (q_1, q_2..........q_L)^T$ for the spectral signatures of two pixel vectors $s_i$ and $s_j$ where $p_k = s_{ik} / \sum_{l=1}^{L} s_{il}$ and $q_k = s_{jk} / \sum_{l=1}^{L} s_{jl}$. So, the self-information provided by $r_i$ and $r_j$ (pixel vectors) for band *l* is defined by (1 and 2) and given by, $I_l(r_i) = - log\, p_l$       (1)

$$I_l(r_j) = - log\, q_l \qquad (2)$$

From (1) and (2), the difference in the self-information of band *l* in $r_j$ relative to the self-information of band *l* in $r_i$ (Cover and Thomas, 1991) is defined by $D_l(r_i \| r_j)$,

$$D_l(r_i \| r_j) = I_l(r_j) - I_l(r_i) = (- log\, q_l) - (- log\, p_l) = log\, (p_l / q_l) \qquad (3)$$

Averaging $D_l(r_i \| r_j)$ in (3) overall bands $1 \leq l \leq L$ with respect to $r_i$ results in

$$D(r_i \| r_j) = \sum_{l=1}^{L} p_l D_l(r_i \| r_j) = \sum_{l=1}^{L} p_l (I_l(r_j) - I_l(r_i))$$

$$= \sum_{l=1}^{L} p_l \, log\, (p_l / q_l) \qquad (4)$$

Where $D(r_i \| r_j)$ is the average difference in the self-information of $r_j$ relative to the self-information of $r_i$. $D(r_i \| r_j)$ in (4), which is also known as Kullback-Leibler information measure, (Kullback, 1997). Average discrepancy in the self-information of $r_j$ relative to the self-information of $r_i$ by,

$$D(r_j \| r_i) = \sum_{l=1}^{L} q_l D_l(r_j \| r_i) = \sum_{l=1}^{L} q_l (I_l(r_i) - I_l(r_j))$$

$$= \sum_{l=1}^{L} q_l \, log\, (q_l / p_l) \qquad (5)$$

Addition of equation (4) and (5) yields SID defined by,

$$SID(r_i, r_j) = D(r_i \| r_j) + D(r_j \| r_i) \qquad (6)$$

Equation (6) can be used to measure the spectral resemblance among two pixel vectors $r_i$ and $r_j$. It should be noted that while SID $(r_i, r_j)$ is symmetric, $D(r_i \| r_j)$ is not. This is because SID$(r_i, r_j)$ = SID $(r_j, r_i)$ but $D(r_i \| r_j)$ $D(r_j \| r_i)$.

## Results and Discussion

Major four groups: HNHW, HNLW, LNHW and LNLW were formed to study the problem of deficiency in Nitrogen and water applied. Differences in vegetation vigour, resulting from variation in nitrogen and water applied, are principally marked when NIR imagery or data are used. Stress is pointed out by progressive decrease in NIR reflectance. Collected spectra for four conditions of crops i.e. HNHW, HNLW, LNHW and LNLW are as shown in Figure 2.
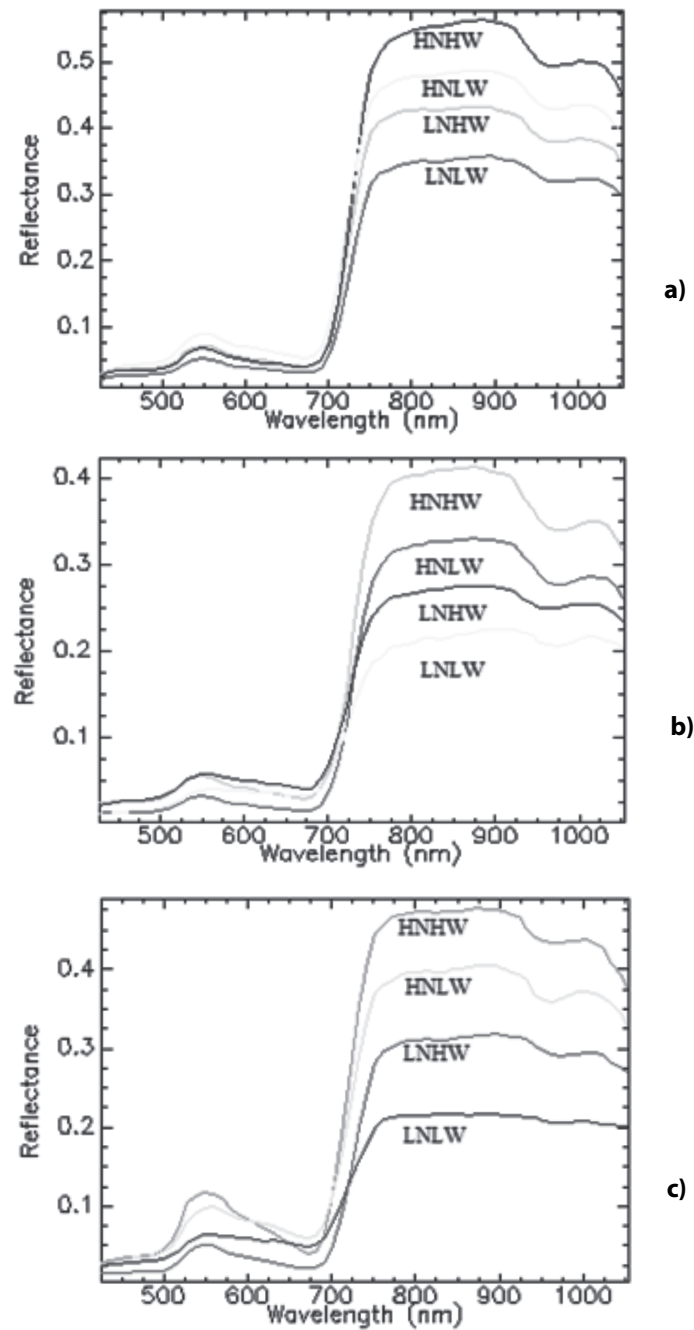
**Figure 2: Crop Field Spectra , a) Chickpea, b) Sorghum and
c) Wheat for Four Conditions HNHW**

Figure 2: Crop Field Spectra , a) Chickpea, b) Sorghum and c) Wheat for four conditions HNHW (High Nitrogen High Water), HNLW (High Nitrogen Low Water), LNHW (Low Nitrogen High Water) and LNLW (Low Nitrogen Low Water) in regulated field plots for nitrogen (as fertiliser) and water variation.

Spectral similarity analysis using SID is carried out between the collected field spectra from regulated field plots of IARI and from the unregulated field plots of study area. Similarity values were computed among various spectra of regulated crop conditions as HNHW, HNLW, LNHW and LNLW and all collected field spectra of study area for a specific crop. Field spectra of the crops were assigned to a regulated crop spectrum of a specific condition where close match has been observed. This analysis was carried out separately for chickpea, sorghum and wheat crops . Based on matching of coefficient of correlation and spectral similarity values, a spectra is assigned to specific crop condition which produces closest match. Similarity results are tabulated in Table 1.

**Table 1: Coefficient of Correlation and SID Spectral Similarity Value Among Crop Field Spectra for Regulated and Unregulated Field Conditions for Nitrogen and Water Variations**

| Closeness Measure / Crops | | Coefficient of Correlation | SID Value (Distance Measure Value) | SID Value Equivalent to Coefficient of Correlation = (1- Distance Measure Value) |
|---|---|---|---|---|
| Chickpea | HNHW | 0.9998 | 0.0003 | 0.9997 |
| | HNLW | 0.9978 | 0.0063 | 0.9937 |
| | LNHW | 0.9995 | 0.0003 | 0.9997 |
| | LNLW | 0.9992 | 0.0004 | 0.9996 |
| Sorghum | HNHW | 0.9992 | 0.0018 | 0.9982 |
| | HNLW | 0.9988 | 0.0019 | 0.9981 |
| | LNHW | 0.9985 | 0.0075 | 0.9925 |
| | LNLW | 0.9955 | 0.0048 | 0.9952 |
| Wheat | HNHW | 0.9968 | 0.0025 | 0.9975 |
| | HNLW | 0.9974 | 0.0157 | 0.9843 |
| | LNHW | 0.9967 | 0.0042 | 0.9958 |
| | LNLW | 0.9978 | 0.0022 | 0.9978 |

Figure 3: Field Crop Spectra of, a) Chickpea, b) Sorghum and c) Wheat for four conditions HNHW, HNLW, LNHW and LNLW developed for unregulated field plots based on spectral similarity with regulated field plots.

Table 1 shows very close match between coefficient of correlation and SID value equivalent to coefficient of correlation derived for crop spectra collected from regulated field conditions and unregulated (study area) field conditions. Average SID measure equivalent to co-efficient of correlation for chickpea was 0.997, for sorghum was 0.996 and for wheat was 0.994. SID similarity among spectra from farmer's fields
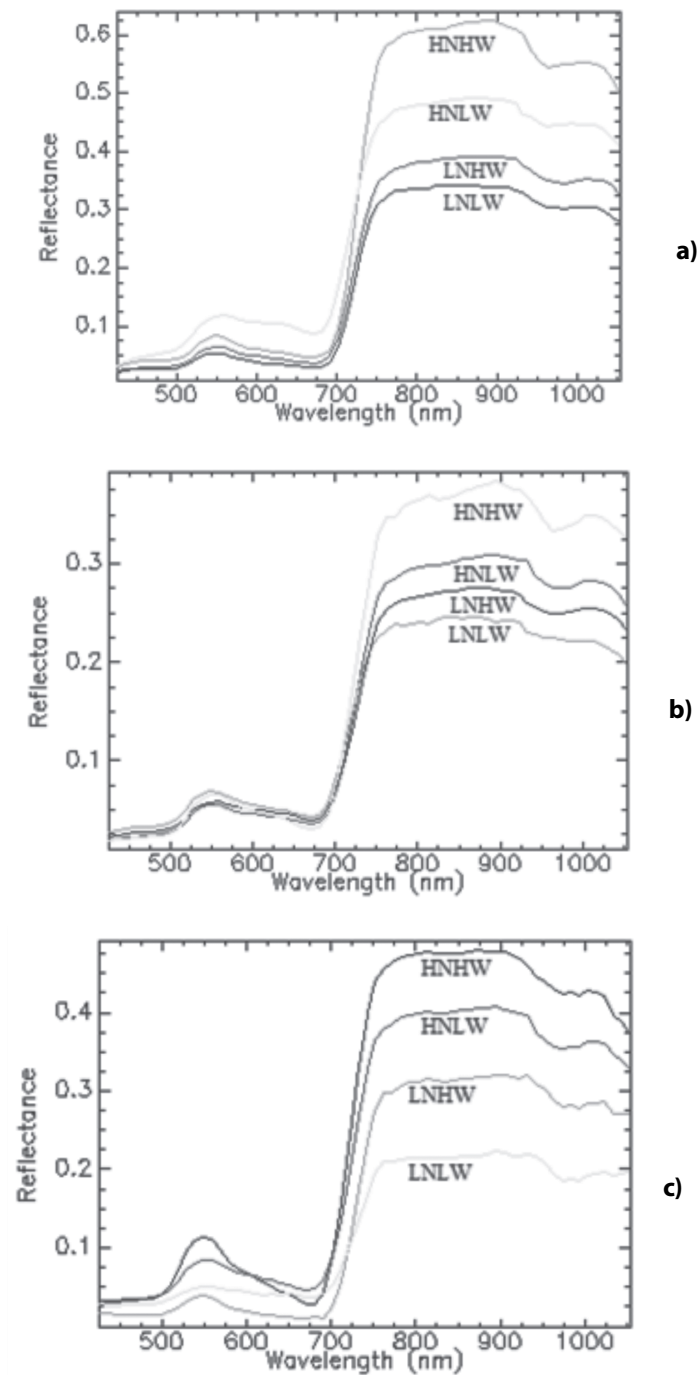
**Figure 3: Field Crop Spectra of, a) Chickpea, b) Sorghum and c) Wheat for Four Conditions**

with spectra from test fields, if crops were water stressed: 0.997 for chickpea, 0.996 for sorghum and 0.991 for wheat. SID similarity among spectra of farmer's and test fields, if crops were Nitrogen stressed: 0.997 for chickpea, 0.994 for sorghum and 0.997 for wheat. This analysis is very much useful to identify water and Nitrogen (Fertiliser) stressed (deficient) areas and timely care leads to sustain crop growth.

Spectral library was built for variation in nitrogen and water for unregulated (study area) conditions as shown in Figure 3. Hence spectral similarity based crop condition analysis provides an effective and possible alternative to quantify field crop condition based on knowledge derived from regulated field conditions. Spectral similarity based crop condition analysis helps to identify field plots with water either/or Nitrogen stressed, crops can be saved if timely care has been taken which helps to sustain agricultural growth for rural development.

## Conclusion

It was quite difficult to develop crop spectra for nitrogen and water variations for actual field conditions as there is large variation in nitrogen (as fertiliser) and water applied. During field visit it was found that despite local conditions being same, crop growth was not uniform in the study area, and this is due to large variation in nitrogen and water applied. Uneven crop growth leads to unsustainable development. Development of crop spectra for nitrogen and water variations for unregulated (study area) field conditions based on spectral similarity analysis with regulated field conditions provides a fresh opportunity to develop and evaluate the crop spectra for nitrogen and water variations for real time applications. The developed spectra helps to identify and classify water and nitrogen (fertiliser) stressed (deficient) areas and timely care leads to sustainable crop growth which ultimately leads to sustainable rural development in agriculture sector.

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