

RETRIVAL OF BIO-PHYSICAL PARAMETERS IN SUNFLOWER CROP (*Helianthus annuus*) USING FIELD BASED HYPERSPECTRAL REMOTE SENSING

Prabhat Kanti Routh^{1,*}, Narayan Chandra Sarkar², Prabir Kumar Das¹, Dipak Debnath², S. Bandyopadhyay¹, Uday Raj³

¹ Regional Remote Sensing Centre- East, National Remote Sensing Centre, Kolkata- prabhatkanti.routh@gmail.com

(prabirkumar_d, bandyo_s)@nrsc.gov.in

² Dept. of Agronomy, Visva Bharati University, Birbhum, India- nciari@gmail.com

³ Regional Centres, NRSC, ISRO, Telengana, India – uday_raj@nrsc.gov.in

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ABSTRACT:

Information on several crop bio-physical parameters is important as inputs for crop growth modelling, leaf stress analysis, crop health study and productivity point of view. Conventionally, biophysical parameters are measured in laboratory methods which are time consuming, laborious and destructive in nature. With the advent of remote sensing technology, the limitations of conventional methods can be overcome. Moreover, due to its narrow absorption bands at different wavelength, use of hyperspectral remote sensing becomes very useful in retrieving several bio-physical parameters. In the present study, field as well as laboratory based spectro-radiometer observations were carried out at Agronomy Department of VisvaBharati University, West Bengal, on Sunflower crop at its peak vegetation stage towards retrieving different bio-physical parameters, specifically leaf area index (LAI), chlorophyll content index (CCI), fluorescence etc. Different foliar boron (no boron, 0.15% and 0.20%) and irrigation (4-6 irrigations) treatments, i.e. total nine treatments with three replications, were applied on sunflower crop during different phenological stages to achieve maximum ranges of the bio-physical parameters. The LAI, CCI and fluorescence parameters were collected using canopy analyzer, chlorophyll content meter and portable gas exchange system, respectively. In each of the treatments, total four hyperspectral measurements were collected, which were further corrected for noise and smoothened using Savitzky-Golay filtering. Total thirty-four narrow band indices were computed based on the hyperspectral data, and the regression analysis was carried out among the indices and bio-physical parameters. The regression parameters were further deployed on the hyperspectral indices to retrieve the bio-physical parameters. The Gitelson & Merzylak-1 (GM-1) and Carter Indices-1 (CI-1) were found to be the best indices for retrieving the LAI and CCI, respectively with correlation correlation (r) values of 0.87 and 0.80. On the other hand, Normalized Phenophytization Index (NPQI) and GM-1 were found to be best for retrieving the Fv/Fm (dark) and Fv'/Fm' (light) with correlation (r) values of 0.92 and 0.76, respectively. Hence, the hyperspectral remote sensing can be successfully utilized for retrieving several bio-physical parameters both at field (canopy level) and laboratory (leaf level) conditions.

1. INTRODUCTION

India is the fourth largest edible oil economy in the world after the USA, Brazil and China. It occupies a distinct position not only in terms of area under oilseed crops, but also in terms of diversity in cultivated oilseeds (<http://agricrop.nic.in>). The country has 19 per cent of world area under oilseeds, which accounts for only 9 per cent of world's production to meet the need of 16 per cent of the population. Nine oilseed crops viz groundnut, rapeseed-mustard, soybean, sesame, linseed, castor, safflower, sunflower and niger grown in India comprise of the second largest commodity after cereal, sharing 14 per cent of the gross cropped area, accounting for 5 per cent of the gross national product and 10 per cent of the value of the agricultural products (www.indialawoffices.com/ilo_pdf/industry_reports/edibleoilindustry.pdf). According to twelfth five year plan it is necessary to produce 40 million tons of oilseeds to maintain parity when examined in the light of fact that the current level of production in these crops is only around 28 million tonnes (<http://gcirc.org/fileadmin/documents/Bulletins/B26/B265RKGupta.pdf>). This wide gap between supply and demand has created due to increasing population improvement in the standard of living and stagnation in production of both

groups of crops. Indian agriculture needs to be more knowledge intensive in order to keep pace with growing population pressure and diminishing land and energy resources. Government of India is giving special importance to enhance their production of oil seed crops mainly to avoid heavy import bill every year. In grey areas of the country, production of oilseeds can be increased by adaption of location-specific cropping systems in which sunflower can be grown in *rabi* season and can be the most important crops of dryland areas with limited water availability under marginal and sub-marginal lands of India. It covers an area around 487.19 thousand hectares and 296.3 thousand MT of total production with 608 kg/ha average productivity in the year of 2015-16 (www.sopa.org/india-oilseeds-area-production-and-productivity/). The existing yield is very low in India, mainly because of the sub-optimal soil fertility. There is ample scope of increasing production by use of agronomic as well as proper fertility management. An advance detection of crop stress is very important to manage the production inputs like water, fertilizer, pesticide for the reduction the risk associated with production of crop. A suitable combination of major and micronutrients is by and large the most important single factor that affects the yield and quality of safflower

*Corresponding author

([www.careratings.com/upload/NewsFiles/SplAnalysis/Outlook of Indian Edible Oil Industry.pdf](http://www.careratings.com/upload/NewsFiles/SplAnalysis/Outlook%20of%20Indian%20Edible%20Oil%20Industry.pdf)). Sunflower (*Helianthus annuus*) is one of the most sensitive crops to low boron supply and applications of fertilizers containing boron increases sunflower production. The boron requirement of sunflower is much higher during reproductive growth compare to vegetative growth, and the malfunctioning of crops due to boron is generally observed during this phenophase. In addition to the boron content of soil, the availability of soil moisture also affects the boron uptake by plants. The health and growth of the crop can be evaluated in terms of different biophysical parameters, LAI, CCI, fluorescence. By adopting remote sensing technology, non-destructive analysis of the plant samples can be carried out toward retrieving the biophysical parameters (<http://www.tandfonline.com/loi/tres20>). Moreover, hyper spectral remote sensing provides information at very narrow spectral interval which may provide useful information for improved discrimination of plant growth status under different irrigation and boron treatments (<http://www.tandfonline.com/loi/tres20>).

Thus, the objectives of this study were to (1) study the effect of irrigation on crop growth and yield (2) study the effect of different level of foliar spray of boron on crop growth (3) explore the potential of hyperspectral remote sensing to capture the impact of boron and irrigation on Sunflower growth and productivity.

1. MATERIALS AND METHODS

1.1 Study Area

The experiment was carried out on sunflower crop (*Helianthus annuus*) in the month of May 2018 at Agronomy department of Visva Bharati University, Birbhum district, West Bengal (Lat 23.6776° N, Long 87.6852°E). The experimental site is representative to determine the optimal doses of irrigation and foliar boron application. The climate is tropical in Bolpur. This climate is considered to be Average Weather according to Koppen Geiger climate classification. The average annual temperature is 26.3° C with average precipitation of 1287mm. The maximum amount of precipitation occurs in July, with an average of 295mm. The experimental fields were composed of 27 plots based on the different levels of irrigation (6, 5, 4 named as M1, M2, M3, respectively) and foliar boron applications (0%, 0.15%, 0.20% named as S1, S2, S3 respectively). There are 3 replicas of above combination of treatments.

1.2 Data collection

Biophysical parameters, viz. Leaf Area Index (LAI) and chlorophyll content index (CCI), and physiological parameters viz. Fluorescence, photosynthesis data along with spectral reflectance observations, were collected during crop peak growing period. LAI was measured using an LAI2200C instrument (Plant Canopy Analyzer). In each plot, the acquisitions were made along a transect composed of one above and three below-canopy readings, and data were post-processed to discard the last ring readings (Stroppiana et al. 2006). Non-destructive measurements of chlorophyll concentration were carried out by relative measurement of transmittance between 931nm and 653nm by means of two light emitting diode in a Chlorophyll meter (MC-100, Apogee Instrument). For each plot, CCI readings were measured on an individual sunflower plant replicated five times, i.e. four at corners and one at the centre of the replica. To avoid the edge

effect, a 50 cm buffer had been taken from all corners of plot. For each plant, CCI readings were collected for the fully expanded first five leaves starting from the top. For physiological parameters, photosynthesis processes are measured like net CO₂ assimilation (A), transpiration (E), stomata conductance (gsw), intercellular CO₂ concentration (C_i), electron transport rate (ETR), non-photochemical quenching (NPQ), quantum yield of photo system II (Φ PSII) and several other processes etc by using portable photosynthesis system LI-6800XTF. An expanded leaf was covered by an aluminium foil to measure dark condition parameters and after 30 minutes of light exposure the photosynthesis parameters for light adapted leaves were measured. Canopy and leaf spectral reflectance were acquired with an SVC HR-1024 (Spectra Vista Corporation) that provides measurements in the 350–2500 nm spectral range with 1.5 nm spectral resolutions and 1 nm sampling step at field and lab. The sensor of the radiometer was placed about 1.00 m above the canopy at nadir position with a viewing angle of 14°, so that the diameter of the footprint is about 0.246 m at field. Five observations within each plot data were collected in order to cover the entire plot and characterize its variability. The average value was taken as the measurement for each of the plot. Measurements were taken between 10:00 and 14:30 hours local time (GMT + 5.5 hour) under clear sky conditions at field. For each plot, radiance from a white reference panel (BaSO₄) was acquired to derive reflectance. Based on reflectance data, various indices are calculated (table-1)

Index Name	Formula
Simple Ratio	$SR = R_{NIR} / R$
Normalized Difference Vegetation Index	$NDVI = (R_{NIR} - R) / (R_{NIR} + R)$
Enhance Vegetation Index	$EVI = 2.5 \times (R_{NIR} - R) / (R_{NIR} + 6 \times R - 7.5 \times R + 1)$
Visible Atmospherically Resistant Index	$VARI = (R - R) / (R + R)$
Normalized Difference Water Index 1	$NDWI1 = (R_{NIR} - R_{NIR}) / (R_{NIR} + R_{NIR})$
Normalized Difference Water Index 2	$NDWI2 = (R_{NIR} - R_{SWIR1}) / (R_{NIR} + R_{SWIR1})$
Normalized Difference Water Index 3	$NDWI3 = (R_{NIR} - R_{SWIR2}) / (R_{NIR} + R_{SWIR2})$
Hyperspectral Vegetation Index	$HVI = (R_{743} / R_{692})$
Hypersepctral Normalized Difference Vegetation Index	$HNDVI = (R_{814} - R_{672}) / (R_{814} + R_{672})$
Greenness Index	$GI = R_{539} / R_{682}$
Hyperspectral Normalized Difference Water Index	$HNDWI = (R_{845} - R_{1256}) / (R_{845} + R_{1256})$
Normalized Difference Infrared Index	$NDII = (R_{845} - R_{1649}) / (R_{845} + R_{1649})$
Water Index	$WI = R_{895} / R_{983}$

Photochemical Reflectance Index	$PRI = (R_{529} - R_{580}) / (R_{529} + R_{580})$
Red-Edge Vegetation Stress Index	$RVSI = 0.5 \times (R_{722} + R_{763}) - R_{733}$
Modified Chlorophyll Absorption Ratio Index	$MCARI = R_{712} \times [(R_{712} - R_{682}) - 0.2 \times (R_{712} - R_{539})] / R_{682}$
Transformed Chlorophyll Absorption Ratio Index	$TCARI = 3 \times \left[\frac{(R_{700} - R_{670}) - 0.2 \times (R_{700} - R_{550})}{(R_{700} - R_{550}) \times \left(\frac{R_{700}}{R_{670}} \right)} \right]$
Triangular Vegetation Index	$TVI = 0.5 \times [120 \times (R_{750} - R_{550}) - 200 \times (R_{670} - R_{550})]$
Zarco-Tejada & Miler	$ZM = R_{750} / R_{710}$
Simple R Pigment Index	$SRPI = R_{430} / R_{680}$
Normalized Phaeophytinization Index	$NQPI = (R_{415} - R_{435}) / (R_{415} + R_{435})$
Photochemical Reflectance Index 1	$PRI1 = (R_{528} - R_{567}) / (R_{528} + R_{567})$
Photochemical Reflectance Index 2	$PRI2 = (R_{531} - R_{570}) / (R_{531} + R_{570})$
Normalized Pigment Chlorophyll Index	$NPCI = (R_{680} - R_{430}) / (R_{680} + R_{430})$
Carter Indices 1	$CI1 = R_{695} / R_{420}$
Carter Indices 2	$CI2 = R_{695} / R_{760}$
Lichtenthaler indices 1	$Lic1 = (R_{800} - R_{680}) / (R_{800} + R_{680})$
Lichtenthaler indices 2	$Lic2 = R_{440} / R_{690}$
Structure Intensive Pigment Index	$SPII = (R_{800} - R_{450}) / (R_{800} + R_{650})$
Vogelmann indices 1	$Vog1 = R_{740} / R_{720}$
Vogelmann indices 2	$Vog2 = (R_{734} - R_{747}) / (R_{715} + R_{726})$
Vogelmann indices 3	$Vog3 = (R_{734} - R_{747}) / (R_{715} + R_{720})$
Gitelson and Merzlyak 1	$GM1 = R_{750} / R_{550}$
Gitelson and Merzlyak 2	$GM2 = R_{750} / R_{700}$

Table-1 List of narrow band indices

2. RESULT AND DISCUSSIONS

The main aim of the study is to retrieve the bio-physical parameters using hyperspectral data. The correlations of the biophysical and physiological parameters with narrow band indices are established. The spectral indices are nondestructive relative scale to detect the crop health in shorter time instead of measuring all parameters by various instruments. To carry out the same following steps were followed-

- Bio-physical parameters (i.e. LAI, CCI) analysis under different treatments
- Physiological parameters (i.e. Fv/Fm, Fv/Fm') analysis under different treatment

c) Calculation of hyperspectral indices and correlation analysis to retrieve of bio-physical and physiological parameters at canopy level.

2.1 Bio-physical parameters

Leaf area index (LAI) is plotted with respect to various treatments (Figure-1). LAI is representative of the vegetative growth and condition of the crops. The higher value of LAI refers to better crop vegetative condition and vice-versa. Leaf area index (LAI) is plotted with respect to the main plot (irrigation condition) and subplot (boron treatment). In case of main plot treatments, it was observed that the LAI values were increasing as the number of irrigations reduced from six (M1) to five (M2). Whereas, with further decrease in number of irrigation, i.e. at four irrigations (M3), the LAI was found to be decreasing.

In case of subplot treatments, it was interesting to find that under M1, i.e. plots with six irrigations, the highest LAI was observed in case of 0.15% foliar application of boron. However, with increase in boron application (0.2%) it was found to be decreasing. Intermediate LAI values were recorded in case of plots with no boron application under M1 treatment. In case of M2, i.e. plots with five irrigations, the highest LAI was recorded in case of crops with maximum (0.2%) boron application, whereas it was almost similar for other two boron treatments, i.e. no and 0.15% boron applications. In case of M3, i.e. plots with four irrigations, the LAI values were found to be increasing with increasing in boron applications (figure-1).

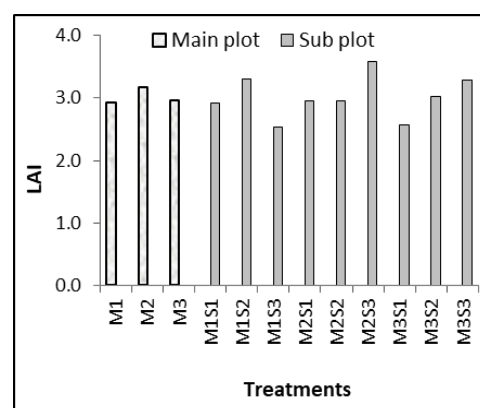


Figure-1 LAI vs Treatments

Chlorophyll Content Index (CCI) indicates the chlorophyll content of crop. The higher values of CCI refer more chlorophyll content of crop and vice-versa. The CCI is quantified as ratio between transmittance at 931nm and 653nm and provides a relative measurement of chlorophyll concentration. Chlorophyll Content Index (CCI) is plotted with respect to the main plot (irrigation condition) and subplot (boron treatment). Under main plot i.e. irrigation treatments, it was observed that the CCI values were increasing as the number of irrigation reduced from six (M1) to five (M2). With further decrease in number of irrigation, i.e. at four irrigations (M3), the CCI was found to be decreasing.

In case of subplot treatments, it was found that under M1, M3 i.e. plots with six and four irrigations, respectively, the highest CCI was observed in case of 0.15% foliar application of boron.

However, with increase in boron application (0.2%) it was found to be decreasing. In case of M2, i.e. plots with five irrigations, the CCI values were found to be increasing with increasing in boron applications (Figure-2).

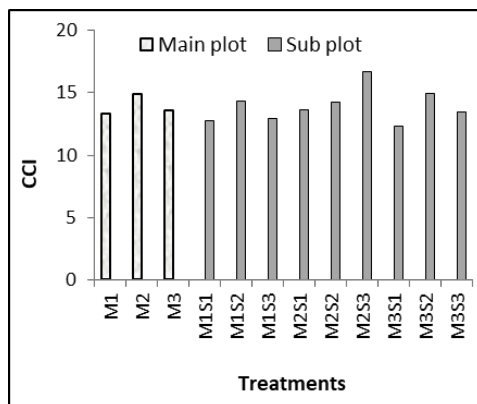


Figure-2 CCI vs Treatments

2.2 Physiological parameters

Fv/Fm is an estimate of the maximum quantum efficiency of PSII reaction centres. This ratio is calculated from two parameters i.e. Fo and Fm. Fo is the fluorescence level of a dark-adapted plant with all PSII primary acceptors 'open' (QA fully oxidized). Fm is the maximal fluorescence level achieved upon application of a saturating flash of light, such that all primary acceptors 'close' (QA fully reduced). Variable fluorescence, Fv, is the difference between Fo and Fm. The variable to maximal fluorescence ratio is normally between 0.75 and 0.85, depending on leaf health, age, and pre-conditioning. It was observed from Figure-3 that Fv/Fm is with normal range of 0.75 to 0.85 for all three types of irrigation. Relatively, M2 was showing better cop health compare to M1 and M3. In sub plot treatments, it was found that no boron and 0.15% boron application were having almost similar Fv/Fm values, whereas for 0.20% boron application lower values were recorded. It was interesting to observe that all three levels of boron applications were having almost similar Fv/Fm values under M2 irrigation treatment. In case of M3, with increased applications of boron the values of Fv/Fm were found to be increasing, representing lesser stress with higher boron applications.

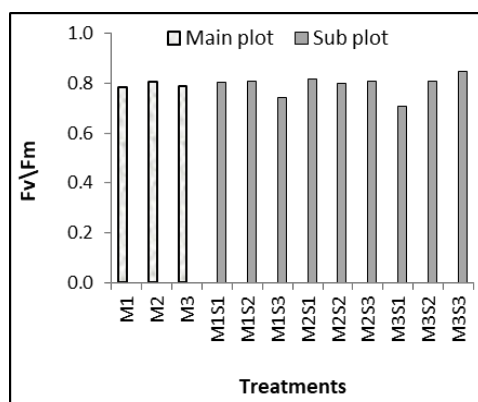


Figure-3 Fv/Fm vs Treatment

Fv/Fm' is the fraction of absorbed PSII photons that are used in photochemistry, and is measured with a light adapted leaf. It is calculated from Fs and Fm', where Fs is steady-state fluorescence and Fm' is the maximum fluorescence from a light adapted sample upon application of a saturating flash. High light adapted plants tend to have low Fv/Fm' values because a higher proportion of the absorbed energy is dissipated through non-photochemical processes. Three other useful fluorescence parameters will be explored in this experiment. Fv/Fm' represents the efficiency of energy harvesting by oxidized (open) PSII reaction centres in the leaf. Two competing processes that quench (decrease) the level of chlorophyll fluorescence in the leaf are referred to as photochemical (qP) and non-photochemical (qN) quenching. All three of these parameters require Fo', the minimal fluorescence (in the dark) of a light-adapted leaf. It was observed from figure-10 that Fv/Fm' is below 0.68 for all three types irrigation. M2 was showing higher value of Fv/Fm' compare to M1 and M3. In sub plot treatments, it was found that no boron and 0.15% boron application were having almost similar Fv/Fm' values, whereas for 0.20% boron application lower values were recorded. It was interesting to observe that all three level of boron applications were having increasing trends Fv/Fm' values under M2 irrigation treatment. In case of M3 irrigation, with increased applications of boron the values of Fv/Fm' were found to be higher than no boron to 0.15% foliar application of boron. However, with increase in boron application (0.2%) it was found to be decreasing (Figure-4).

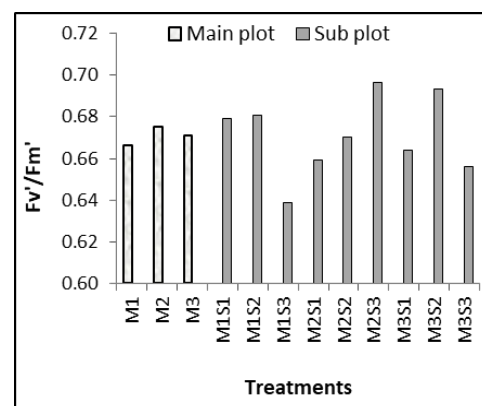


Figure-4 Fv/Fm' vs Treatment

2.3 Retrieval Bio-physical and Physiological parameters

A linear regression was established between the LAI and CCI with individual spectral indices. Similarly, another set linear regression was performed between Fv/Fm and Fv/Fm' with individual spectral indices. Further, multiple regression with all the narrow band indices were carried out to retrieve LAI, CCI, Fv/Fm, Fv/Fm' at canopy level.

Out of these indices it was found some of the indices are having better correlation with LAI and CCI given in table-2. The 90% of significant correlations are given in (**) and 80% are given in (*).

Indices	Canopy	
	LAI	CCI
	r-value	r-value

CI1	0.09	-0.74**
CI2	0.30*	-0.69**
GI	0.01	0.30*
GM1	0.40**	0.60**
GM2	-0.38*	0.62**
PRI	0.09	0.29
PRI1	-0.13	0.77**
PRI2	-0.21	0.77**
RVSI	0.39**	0.25
SIPI	-0.42**	0.61**
SRPI	-0.10	0.78**
TVI	-0.02	0.53**
VARI	0.03	0.26*
VI1	-0.33*	0.61**
VI2	0.31*	-0.57**
VI3	0.31*	-0.57**
WI	0.08	0.02
ZM	-0.34*	0.63**

Table-2 Correlation coefficient between narrow band indices and bio physical parameters

For LAI retrieval Structure Intensive Pigment Index (SIPI), Red-Edge Vegetation Stress index (RVSI), Gitelson and Merzlyak1 (GM1), Gitelson and Merzlyak2 (GM2) and Zarco-Tejada & Miler (ZM) showed higher correlation than other indices.

Gitelson and Merzlyak1 (GM1) is plotted with Leaf Area Index (LAI) with regression value $r=0.40$ as shown in Figure-5.

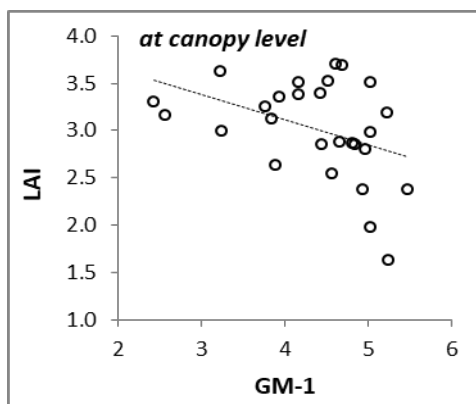


Figure-5 LAI vs GM-1

For CCI retrieval Carter Indices 1 (CI1), Carter Indices 2 (CI2), Photochemical Reflectance Index 1 (PRI1), Photochemical Reflectance Index 2 (PRI2) and Simple R Pigment Index (SRPI) showed higher correlation than other indices.

Simple Ratio Pigment Index (SRPI) is plotted with Chlorophyll Content Index (CCI) with regression value $r=0.78$ (Figure-6).

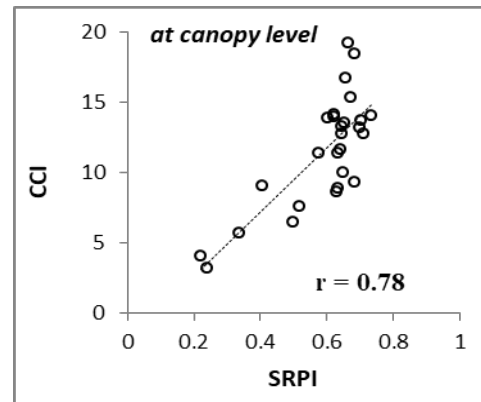


Figure-6 SRPI vs CCI

Out of these indices it was found some of the indices are having better correlation with Fv/Fm and Fv'/Fm' given in table-3 for dark and light condition of leaf. About 90% of significant correlations are given in (**) notation and 80% are given in (*).

Indices	Canopy	
	Fv/Fm	Fv'/Fm'
	r-value	r-value
VARI	0.04	0.13
GI	0.01	0.22
ZM	-0.25	-0.40*
SRPI	0.11	-0.35
NPQI	-0.41**	0.13
NPCI	-0.07	0.36
CI1	-0.10	0.38*
CI2	0.24	0.42**
LI1	-0.26	-0.41*
LI2	0.10	-0.35
SIPI	-0.38*	-0.37
VI1	-0.25	-0.39*
VI2	0.25	0.37*
VI3	0.25	0.37*
GM1	-0.30*	0.44**
GM2	-0.27*	-0.39*
PRI1	-0.06	-0.40**
PRI2	-0.13	-0.39*
RVSI	0.38*	0.39*

Table-3 Correlation coefficient between narrow band indices and physiological parameters

Once again to retrieve Fv/Fm, Normalized Phaeophytinization Index (NPQI), Structure Intensive Pigment Index (SIPI), Red-Edge Vegetation Stress index (RVSI), Gitelson and Merzlyak1 (GM1), and Gitelson and Merzlyak2 (GM2) showed higher correlation than other indices.

Normalized Phaeophytinization Index (NPQI) is plotted with Fv/Fm for dark condition with regression value $r = -0.41$ (Figure-7).

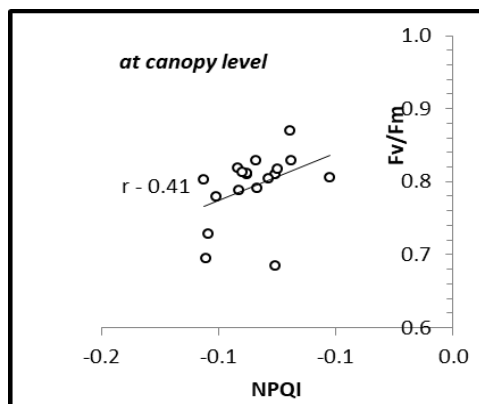


Figure-7 Fv/Fm vs NPQI

Similar way again to retrieve Fv'/Fm', Zarco-Tejada & Miler (ZM), Lichtenthaler indices 1 (LI 1), Photochemical Reflectance Index 1 (PRI1), Gitelson and Merzlyak1 (GM1), and Carter Indices 2 (CI2) showed higher correlation than other indices.

Gitelson and Merzlyak1 (GM1) is plotted with Fv'/Fm' for light condition with regression value $r = 0.44$ (Figure-8).

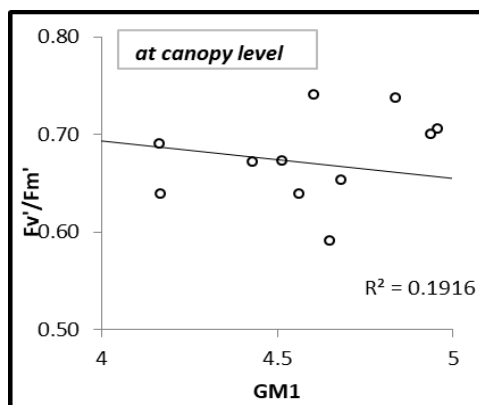


Figure-8 Fv'/Fm' vs GM1

The results obtained from multiple regressions are given in Table-4.

Parameters	Correlation	Indices
LAI	0.87	RVSI, SIPI, CI-2, GM-1, ZM, PRI-1 (Refer -9)
CCI	0.79	SRPI, RVSI (Refer-10)
Fv/Fm	0.92	RVSI, SRPI, PRI-2, NPQI, SIPI, VI-3, ZM (Refer -11)
Fv'/Fm'	0.76	RVSI, GM-1, GM-2, CI-1 (Refer-12)

Table-4 Multiple regressions

The biophysical parameters, LAI & CCI and physiological parameters, Fv/Fm & Fv'/Fm' were retrieved using the identified indices along with the regression parameters (Figure-9 to 12) It was found the narrow band indices were able to retrieve both bio-physical and physiological parameters with high accuracy.

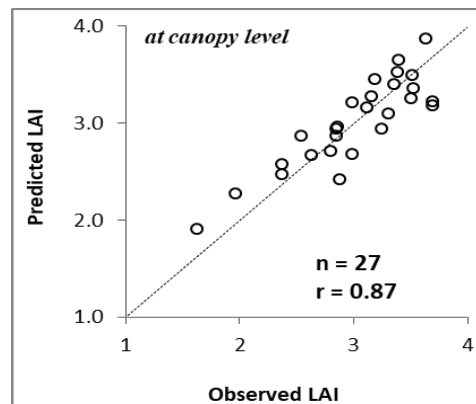


Figure-9 Predicted LAI vs Observed LAI

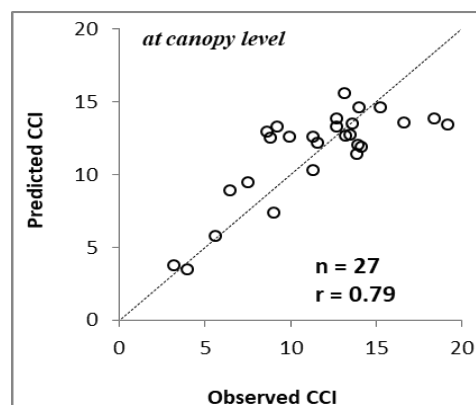


Figure-10 Predicted CCI vs Observed CCI

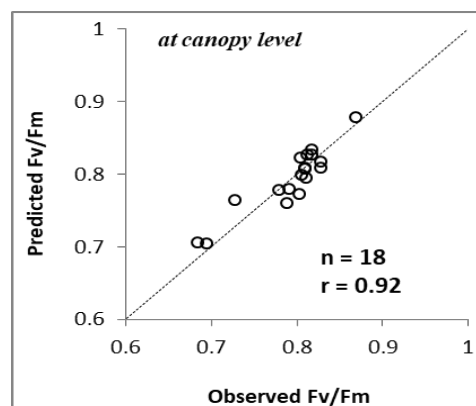


Figure-11 Predicted Fv/Fm vs Observed Fv/Fm

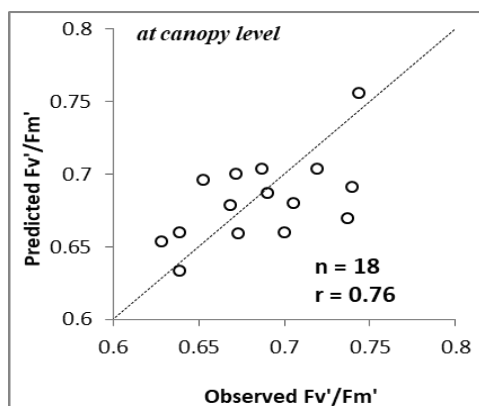


Figure-12 Predicted Fv/Fm' vs Observed Fv/Fm'

3. CONCLUSION

M2 i.e. medium irrigation is found to be optimum for better crop health which is reflected in terms of bio physical and physiological parameters in both LAI and CCI. Moreover, M2S3 is found to be even better combination for growth of sun flower crop. Narrow band indices were derived and linear as well as multiple regressions were carried out. It was found five indices i.e. Structure Intensive Pigment Index (SIPI), Red-Edge Vegetation Stress index (RVSI), Gitelson and Merzlyak1 (GM1), Gitelson and Merzlyak2 (GM2) and Zarco-Tejada & Miler (ZM) are able to retrieve bio-physical parameter (LAI) with higher accuracy. Whereas, Carter Indices 1 (CI1), Carter Indices 2 (CI2), Photochemical Reflectance Index 1 (PRI1), Photochemical Reflectance Index 2 (PRI2) and Simple R Pigment Index (SRPI) indices are able to retrieve CCI in linear regression with 80 to 90% accuracy. Similar way, physiological parameters are also retrieved in linear regression fit for both light and dark condition i.e. Fv/Fm' and Fv/Fm respectively. The multiple regressions also followed to retrieve narrow bio-physical and physiological parameter from 76 to 92% accuracy. Overall, the narrow band indices were able to retrieve both bio-physical and physiological parameters with high accuracy.

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