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Research Article

USE OF CANOPY REFLECTANCE AT DIFFERENT GROWTH STAGE FOR ESTIMATION WHEAT YIELD

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Abstract: It is difficult to predicting grain yield of wheat for a large area because the relationship may not be stable even if information on surface cover type is used. Remote sensing observations were found successful for reliable and quantitative estimates of canopy biophysical properties. Keeping this in view a study was planned in village Halali of district Raisen. The study area belongs to eastern part of the fertile Vindyanchal Plateau. This study has been done for the data collected during humid subtropical climate with cool, dry winter's a hot summer and a humid monsoon season. The plant bio physical parameters were taken from LAI meter, Chlorophyll meter and Spectroradiometer. These parameters were taken as input parameters for PROSIAL model. The output of this model was recorded as simulated data. The simulated data & ground data were used to get R2 by linear correlation. Relationships between wave length and spectral response were drawn by relative spectral response (RSR) for 2nm intervals using Lagrange's interpolation scheme. The empirical regression models were developed for the study area by using in situ field observation and LAI was calculated during growing to harvesting crop season 2015-2016. The spatial resolution of AWiFS (56m) was adequate enough to ensure relatively accurate retrials of LAI of wheat crop at regional scale. The AWiFS has a 5- days revisit period which may cause loss of data due to persistent cloud or fog and to assess. However, the Resoures at-2 increases the possibility to get clear sky data availability. The linear correlation between simulated and ground data during the wheat growing season gave high coefficient of determination (R2= 0.99) in SWIR band.

Keywords: LAI meter, Chlorophyll meter and Spectroradiometer

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Introduction

Wheat (*Triticum aestivum* L.) is one of the most important widely grown cereal grain crop occupying 17 % of the total cultivated land in the world. It is a major staple food for 35% of the world population and provides more calories and protein in the world's diet than any other crop [1]. Global wheat production in 2013-14 was 717 million tones and forecast to around 718.5 million tones in 2014-15 [2]. India is one of the main wheat producing and consuming countries of the world. In India, wheat is grown over 30 million ha (58% of the net cropped area during Rabi) with a production of 94 million tons and contributing about 43% to the country's granary [3]. India's second rank in global wheat production after China and it share about 13.1% in global wheat production and about 3.16 % share for global wheat export in the year 2013-14 [4] In 2013-14 Madhya Pradesh wheat production was 13.93 million tones on 5.79 million ha with a productivity of 2405 Kg per ha. In Madhya Pradesh, wheat acreage increased by 9.28 % but decline in the crop yield by 2.96 per cent in 2013-14 over 2012-13 [5]. There are many studies supporting this, conducted on a wide array of crops and their biophysical and biochemical variables such as yield [6,7], chlorophyll content [8], nitrogen content [9,10], carotenoid pigment1, plant biotic stress [11, 12], plant moisture [13] and other biophysical variables [14]. The development of spectral library using hyperspectral data is another emerging component [15]. The empirical relationship of vegetation indices and biophysical parameters is sensitive to vegetation type and soil background. It is difficult to apply to a large area because the relationship may not be stable even if information on surface cover type is used.

Material and Method

Study Area

The Wheat study site is located in village Halali of district Raisen (latitude 23°28'.24'' N longitudes 77°35'.35'') situated at 417m above the sea level. The Halali field covers an area of 8 ha which is situated in Eastern part of the fertile Vindhyanchal Plateau. This study was done for the data collected during humid subtropical climate with cool, dry winters, a hot summer and a humid monsoon season. These data were collected during rabi seasons *i.e*. from December to March in winter when average temperature was 23°C with little or some rainy days for each aforesaid crop *i.e*. Wheat.

Scientific Instruments Used

LAI observation

In each subplot, LAI was non-destructively measured using a widely used optical instrument, the Plant Canopy Analyzer LAI-2000 (LICOR Inc., Lincoln, NE, USA). A detailed description of this instrument is given by LI-COR (1992) and Welles and Norman (1991). In this study, measurements were taken either under clear skies with low solar elevation (*i.e*., within the two hours following sunrise or preceding sunset) or under overcast conditions. The LAI measurements were taken on the same day that the canopy spectral measurements were made. To prevent direct sunlight on the sensor of LAI-2000, samples of below- and above-canopy radiation were made in the direction facing away from the sun (*i.e*., with the sun behind the operator), using a view restrictor of 45°C. For each subplot, reference samples of above-canopy radiation were determined by measuring incoming radiation above the grass subplot (in an open area). Next, five below-canopy samples were collected and used to calculate the average LAI.

Chlorophyll observation

The total canopy chlorophyll content (CCC; units: g m-2) for each subplot was obtained by multiplying the leaf chlorophyll content by the corresponding LAI.

Spectroradiometer observation

The Spectrolon Spectroradiometer is used for the measurement of reflectance, radiance, or irradiance. It is a compact, field portable and precision instrument with a spectral range of 350-2500 nm. One of the major applications for remote sensing kkjj technology is vegetation studies. Remote sensing using a field spectroradiometer, like the PSR+ 3500, can be applied to management of land and water resources, disaster assessment, yield production, canopy studies, crop yield forecasting, vegetation identification and crop condition assessment.

Principle of measurement

Light energy is collected through a short solid core of specially formulated optical fibre which is precisely cut, polished and sealed for the most efficient energy collection. It is called Bare Head. The fibre itself is a "water-free" composition providing the lowest NIR light attenuation available. The bare head and the optional detachable fibre optic cable have a conical view subtending a full angle of about 25 degrees.

Canopy Reflectance

Canopy radiative transfer (CRT) model

One dimensional canopy radiative transfer simulation models, PROSIAL, is the combined from of PROSPECT and SAIL. The PROSPECT simulates reflectance at leaf level and SAIL (scattering by arbitrary inclined leaves) addresses the directionality. The PROSPECT pioneered the simulation of directional-hemispherical reflectance and transmittances [16] of various green monocotyledonous and dicotyledonous species, as well as senescent leaves [17], over the vegetation senescent solar spectrum from 400 nm to 2500 nm [18]. It is primarily based on the representation of the leaf as one or several absorbing thin plates with rough surface giving rise to isotropic scattering [19].

PROSAIL forward simulation

The PROSIAL model uses chlorophyll a + b (cab), water (cw) and biomass (cm) specific absorption coefficient to simulate canopy reflectance at 2nm interval over 400- 2500nm. In order to simulate band averaged reflectance of AWiFS spectral bands, the sensor spectral convolution was done in the model. AWiFS sensor spectral was initially available at 2 nm from laboratory. As per the model requirement it was converted at 5 nm interval using lag ranges interpolation scheme. The interpolated spectral response was initially available at 2 nm from laboratory. As per the model requirement it was converted at 5 nm response and no loss of spectral information was observed at 5nm. The various input parameters listed were divided into number of intervals within their theoretical lower and higher limits to cover whole dynamics of wheat growth. The limits had been fixed on the basis of field measurements over wheat crop during 2005-2006 and 2006-2007 and reports from scientific community [20-24]. For two different agro-climatic regions, two distinct soil spectral libraries [25] was used as an input for running the model over particular region. All the combinations of different inputs according to their limits and intervals resulted 2,000,000 input scenarios for wheat crop. The model was running in forward mode to generate simulated reflectance for four AWiFS spectral bands from 2,000,000 scenarios for respective soil types of the region. Each set of simulated AWiFS reflectance's generated through forward runs correspond to unique sets of input parameters. Since present study aimed at retrieval of LAI, a look up table (LUT) was constituted from this simulated database of canopy reflectance and respective input parameters. The observed surface reflectance in four brands from AWiFS was used to retrieve

LAI from LUT inversion

Wheat crop map was applied over each date for the retention of wheat pixels for LAI retrievals. While inversion, AWiFS surface reflectance's the whole set of reflectance in the simulated database of LUT. A cost function (S) was used that represented the sum of square differences between AWiFS pixel band reflectance's and model simulated band reflectance's. Minimum of the cost function was obtained using least square approach which gives a unique value of LAI for a given set of observed reflectance. This approach is similar to the variational method in difference of error is minimize but differ in the sense of observation error covariance matrices. This may be the scope of future research under that variational approach [26] and can be used to retrieve the LAI from observed reflectance. In variational method, cost function, which is the function of total variance, is minimized [27-30].

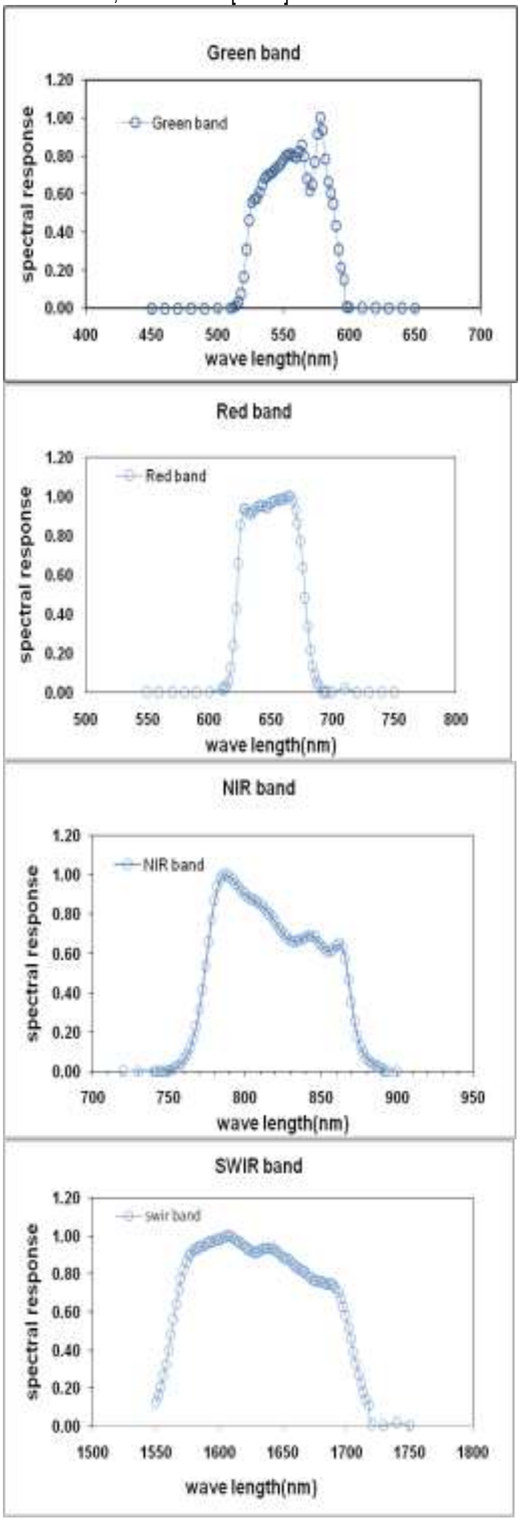


Fig-1 Relative Spectral Response (RSR) for 2 nm Intervals Using Lagrange's Interpolation Scheme.

Satellites Data

The sites developed and given in this document could be utilized for Resourcesat-2 (AWiFS).the advanced wide-field sensor (AWiFS) sensor on–board satellite observe earth's surface in four optical bands (green (0.52-0.59μm), red (0.62-0.68 μm), NIR (0.77-0.86μm), SWIR (1.55-1.70μm)) having spatial resolution of 56 m.

Table-1 Specifications of the Satellite Sensors

Resourcesat-2				
AWiFS (56m)	Central wavelength (nm)*	Nominal bandwidth (nm)	Lmax (mw/cm²/sr/µm)	Lmin (mw/cm²/sr/µm)
B2-green	558	520 – 590	52.00	0
B3-red	654	620 – 680	47.00	0
B4-nir	821	770 – 865	31.50	0
B5-swir	1629	1550 – 1700	7.50	0

Table-2 Chlorophyll Content on Different Dates During Crop Growth

Chlorophyll content (micro gram /cm²)				
Field	10/12/2015	5/1/2016	25/01/16	1/3/2016
F1	55.13	32.49	29.01	30.65
F2	58.43	48.69	26.42	22.33
F3	73.25	36.75	33.65	26.40
F4	60.63	45.49	30.25	26.98
F5	69.77	45.89	29.29	24.14
Mean	63.44	41.86	29.73	26.10
SD	7.72	6.89	2.61	3.15
CV%	12.17	16.46	8.79	12.06
Median	60.63	45.49	29.29	26.40

Table-3 Leaf Area Index on Different Dates During Crop Growth

Leaf Area Index					
Field No.	10/12/2015	5/1/2016	25/01/16	1/3/2016	15/03/16
F1	1.30	3.85	4.12	4.00	1.68
F2	1.48	1.14	4.52	2.23	1.98
F3	1.67	1.58	3.07	3.54	1.78
F4	1.63	2.21	3.83	3.11	1.87
F5	1.43	2.74	2.82	3.59	1.76
Mean	1.50	2.30	3.67	3.29	1.81
SD	0.15	1.06	0.71	0.68	0.11
CV%	10.06	45.94	19.41	20.51	6.17
Median	1.48	2.21	3.83	3.54	1.78

Table-4 Grain Yield on Different Fields

Field	Grain yield (kg ha^{-1})	Grain yield/Field(kg)	Grain yield/plant(gm)
F1	4300	43.00	5.90
F2	4140	41.40	6.76
F3	3720	37.20	5.45
F4	3140	31.40	5.40
F5	2520	25.20	5.67
Mean	3564.00	35.64	5.84
SD	736.12	7.36	0.55
CV%	20.65	20.65	9.48
Median	3720.00	37.20	5.67

Table-5 Error Statistics in Different Bands of AWiFS on 15.12.15

Bands	Equation	Multiple R	R Square	Adjusted R Square	Standard Error	Observation
Green	y = 0.843x + 0.014	0.90	0.81	0.80	0.00286	15
Red	y = 0.776x + 0.018	0.99	0.99	0.99	0.000248	13
NIR	y = 0.576x + 0.076	0.94	0.90	0.89	0.00086723	19
SWIR	y = 0.792x + 0.013	0.99	0.99	0.99	0.00057798	31

Table-6 Error Statistics in Different Bands of AWiFS on 05.01.16

Bands	Equation	Multiple R	R Square	Adjusted R Square	Standard Error	Observations
Green	y = 0.812x + 0.007	0.93	0.87	0.86	0.002685049	15
Red	y = 0.873x + 0.005	0.99	0.99	0.99	0.000212959	13
NIR	y = 0.479x + 0.153	0.78	0.62	0.59	0.001825288	19
SWIR	y = 1.048x - 0.133	0.97	0.95	0.94	0.003828022	31

Table-7 Error Statistics in Different Bands of AWiFS on 25.01.16

Bands	Equation	Multiple R	R Square	Adjusted R Square	Standard Error	Observations
Green	y = 0.817x + 0.001	0.96	0.93	0.92	0.002272501	15
Red	y = 0.692x + 0.006	0.99	0.99	0.99	0.000346004	13
NIR	y = 0.615x + 0.167	0.75	0.57	0.54	0.003189554	19
SWIR	y = 1.002x - 0.091	0.98	0.97	0.96	0.003649061	31

Table-8 Error Statistics in Different Bands of AWiFS on 01.03.16

Bands	Equation	Multiple R	R Square	Adjusted R Square	Standard Error	Observations
Green	y = 0.508x + 0.012	0.93	0.88	0.87	0.001754877	15
Red	y = 0.598x + 0.009	0.99	0.99	0.99	0.000163418	13
NIR	y = 1.366x - 0.137	0.78	0.61	0.58	0.007567038	19
SWIR	y = 0.915x - 0.143	0.87	0.76	0.75	0.007524858	31

Table-9 Error Statistics in Different Bands of AWiFS on 15.03.16

Bands	Equation	Multiple R	R Square	Adjusted R Square	Standard Error	Observations
Green	y = -0.263x + 0.093	0.21	0.045	-0.028	0.009759894	15
Red	y = -1.002x + 0.144	0.95	0.91	0.91	0.001286836	13
NIR	y = 1.839x - 0.413	0.92	0.85	0.84	0.004258998	19
SWIR	y = 0.771x - 0.005	0.95	0.90	0.90	0.003126781	31

AWiFS have a radiometric resolution of 12 bits has swath of 740km with five day receptivity. The cloud free AWiFS data [Table-1] the central wavelength, bandwidth, Lmax and Lmin, and spatial resolution of these satellite-sensors are given below in [Table-1].

Results and Discussion

Chlorophyll content (micro gram /cm2)

The data on chlorophyll content recorded at different dates and fields are presented in [Table-2].The data are also graphically depicted and presented in [Fig-2]. It is observed for [Table-2]. That the average chlorophyll content of all field is maximum on 10/12/2016 *i.e.* 63.44, SD 7.72 and CV is maximum on 5/1/2016 16.46, and the average chlorophyll content of all field is minimum on 1/3/2016 *i.e.* 26.10, SD 25/1/2016 2.61 and CV 8.79.The chlorophyll content is highest in tillering to booting stage and lowest chlorophyll content is milking to maturity stage.

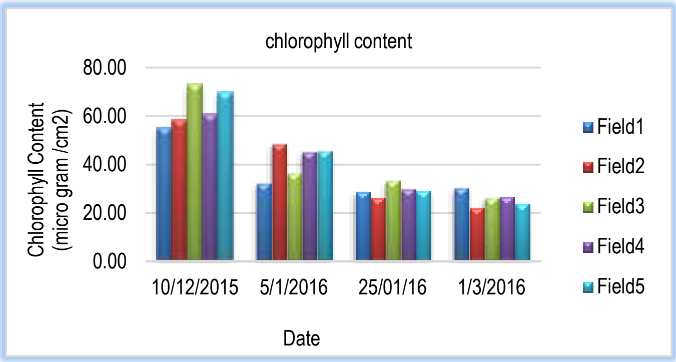


Fig-2 Chlorophyll Content at Different Dates.

Leaf area index

The data on leaf area index recorded at different dates and fields are presented in [Table-3].The data are also graphically depicted and presented in [Fig-3]. It is observed for [Table-3]. That the leaf area index higher so crop is healthy condition. Average leaf area index of all field is maximum on 25/1/2016 *i.e.* 3.67, SD 0.71 and CV is maximum on 5/1/2016 45.94, and the average leaf area index of all field is minimum on 10/12/2015 *i.e.* 1.50, and SD, CV on 15/3/2016 *i.e.* 0.11, 6.17.

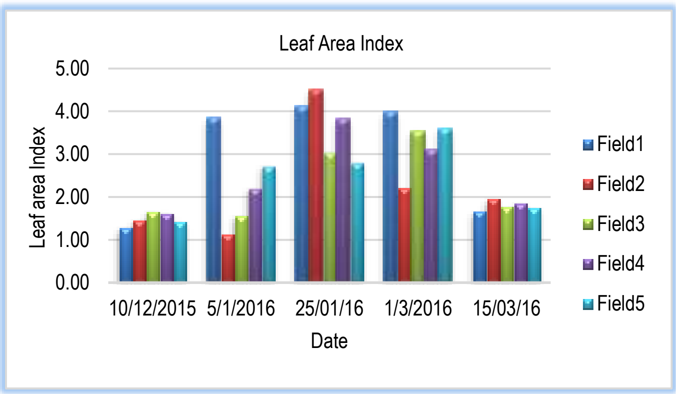


Fig-3 Leaf Area Index at Different Dates

Grain yield (kg ha-1)

The data pertaining on grain yield of wheat are presented in [Table-4] The data are also graphically depicted and presented in [Fig-4]. In present study the highest grain yield is recorded in field F1 that is (4300 kg ha-1) and the lowest grain yield is recorded in field F5 that is (2520 kg/ ha-1).

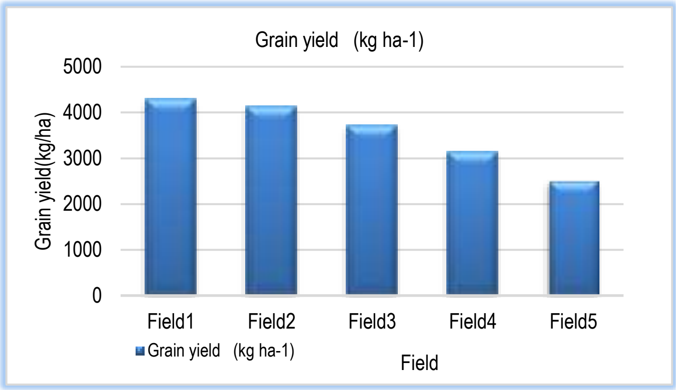


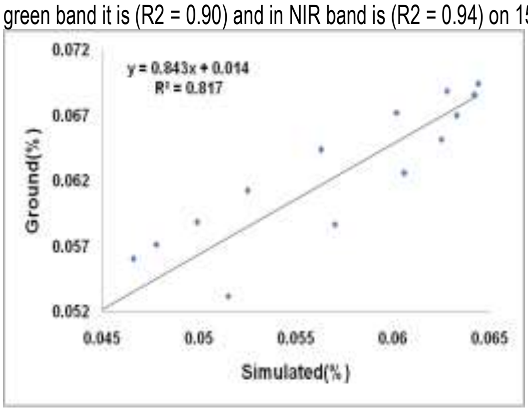
Fig-4 Grain Yield on Different Field.

Comparison of ground observed LAI Vs PROSIAL model simulated LAI for AWiFS sensor bands on different dates.

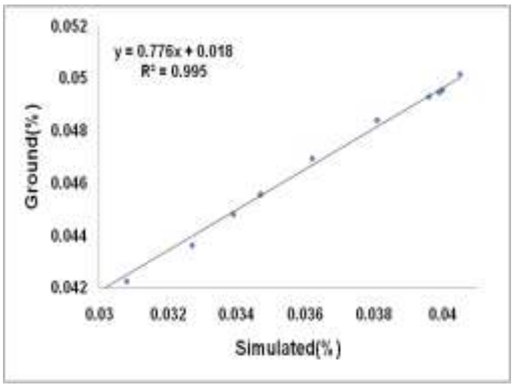
[Fig-3] Shows the linear correlation between simulated and ground data during the wheat growing season and give high coefficient of determination R2.Relationship between simulated and ground reflectance are depicted in [Fig-4], [Fig-5], [Fig-6] and [Fig-7].

Comparison of ground and PROSIAL simulated reflectance at different dates of sowing at different bands of AWiFS sensor.

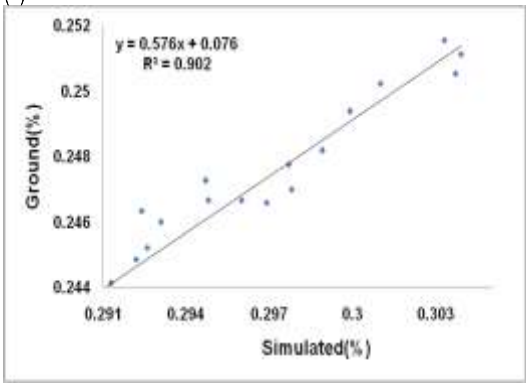
Homogeneous wheat patches comprising of 3 * 3 pixels over measurement sites as described in section "*In situ* data: sampling strategy" were marked as regions of interest (ROI) on AWiFS image using geographical positioning system co-ordinates. Four band (Green, Red, NIR, SWIR) surface reflectance generated through spectroradiometer and output of PROSIAL model correlated for different dates and bands. Maximum R2 values in red and SWIR band (R2= 0.99) and for green band it is (R2 = 0.90) and in NIR band is (R2 = 0.94) on 15/12/2015.



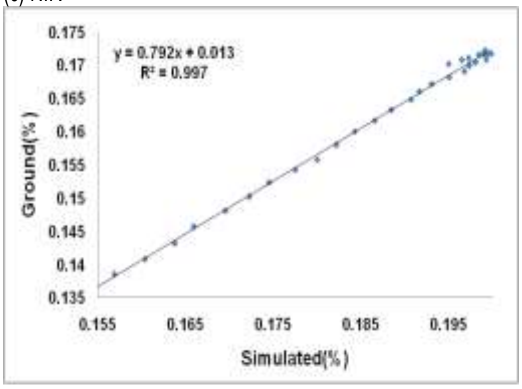
(a) GREEN



(b) RED



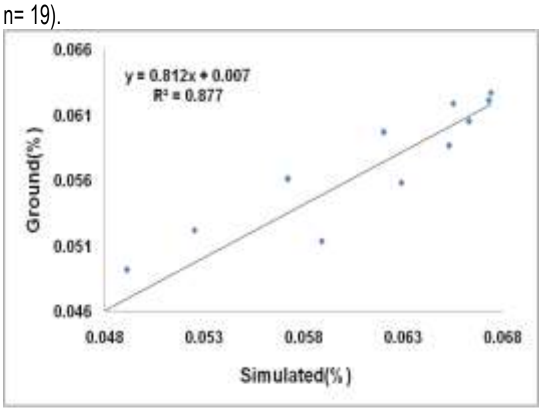
(c) NIR



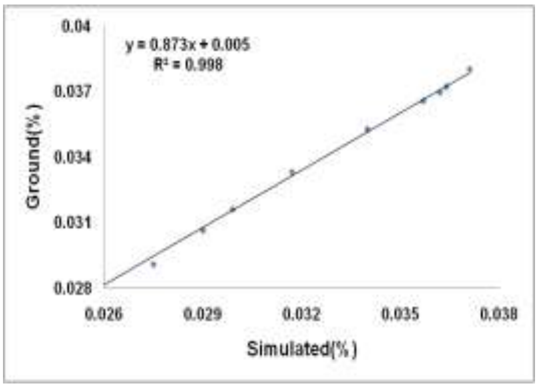
(d) SWIR

Fig-5 Relationship between Ground Reflectance and Simulated Reflectance on 15.12.15

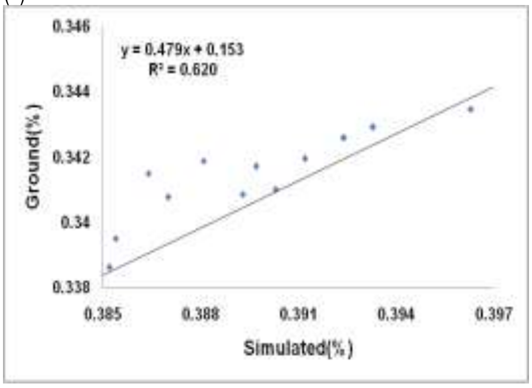
The MODIS 05/01/2016 date simulated and ground were validated with in situ observation collected over a limited area during 2016 wheat seasons. In situ diurnal ground at spectroradiometer and simulated at PROSIAL model were collected as per the sample design give for LAI. For date 05/01/2016 and best band is red band ($R2 = 0.99$, $n=13$) and lowest R2 values is NIR band ($R2=0.62$, $n= 19$).



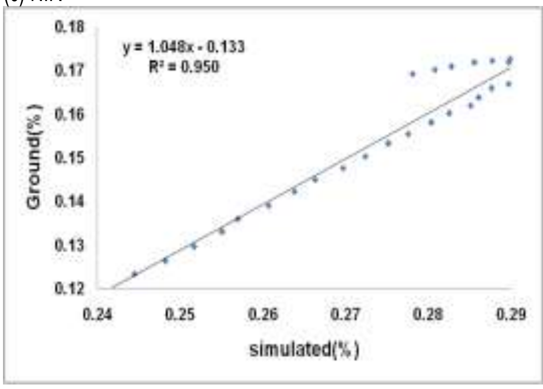
(a) GREEN



(b) RED



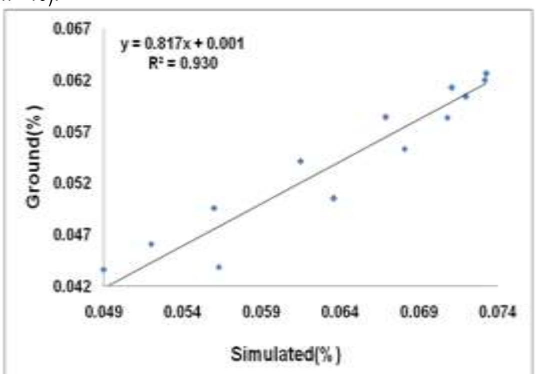
(c) NIR



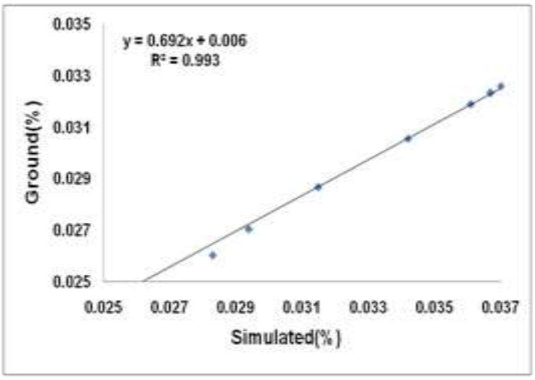
(d) SWIR

Fig-6 Relationship between Ground Reflectance and Simulated Reflectance on 05.01.16

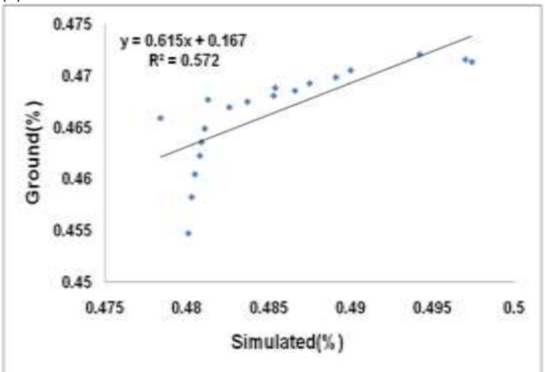
The MODIS 25/01/2016 date simulated and ground were validated with in situ observation collected over a limited area during 2016 wheat seasons. In situ diurnal ground at spectroradiometer and simulated at PROSIAL model were collected as per the sample design give for LAI. For date 05/01/2016 and best band is red band ($R2 = 0.99$, $n=13$) and lowest R2 values is NIR band ($R2=0.75$, $n= 19$).



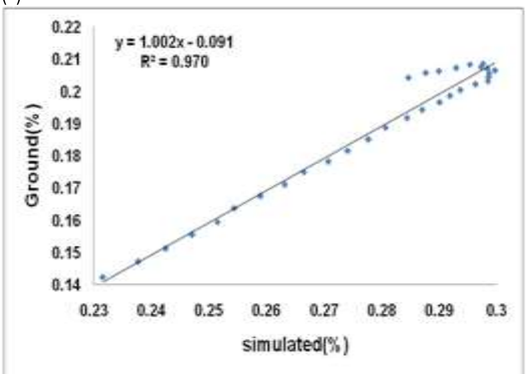
(a) GREEN



(b) RED



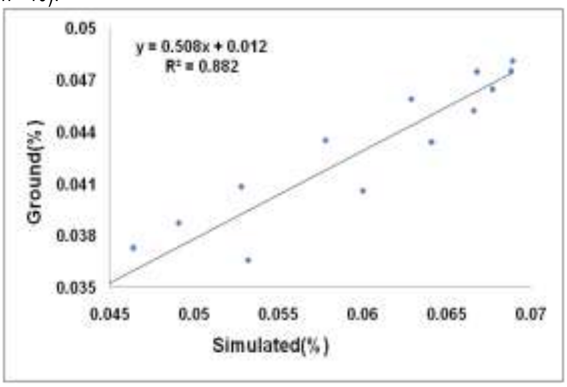
(c) NIR



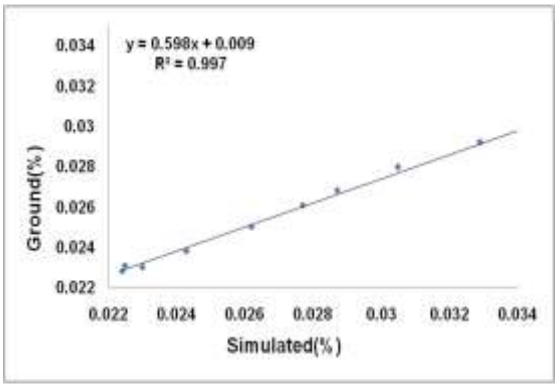
(d) SWIR

Fig-7 Relationship between Ground Reflectance and Simulated Reflectance on 25.01.16

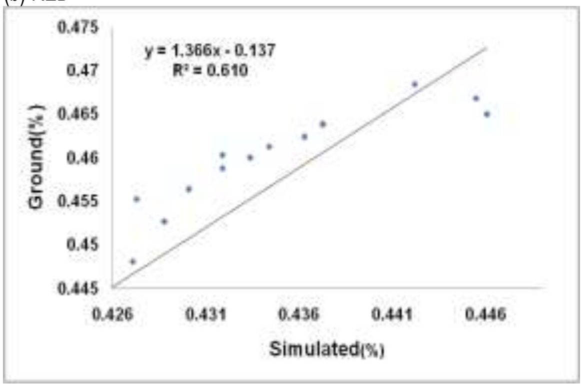
The MODIS 01/03/2016 date simulated and ground were validated with in situ observation collected over a limited area during 2016 wheat seasons. In situ diurnal ground at spectroradiometer and simulated at PROSIAL model were collected as per the sample design give for LAI. For date 05/01/2016 and best band is red band (R2 = 0.99, n=13) and lowest R2 values is NIR band (R2=0.78, n= 19).



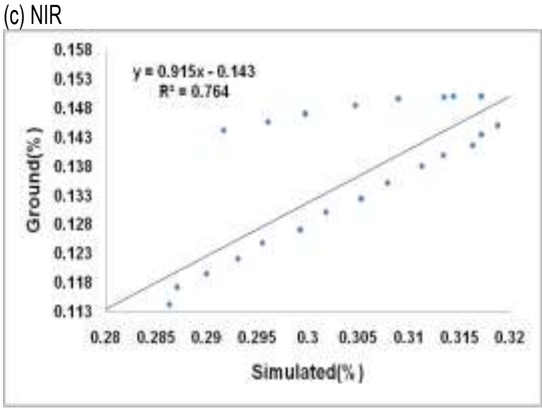
(a) GREEN



(b) RED



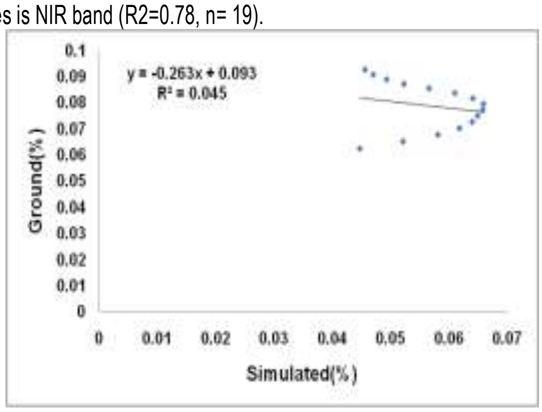
(c) NIR



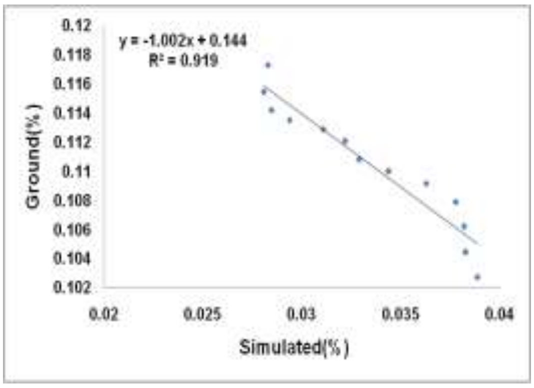
(d) SWIR

Fig-8 Relationship between Ground Reflectance and Simulated Reflectance on15-03-201

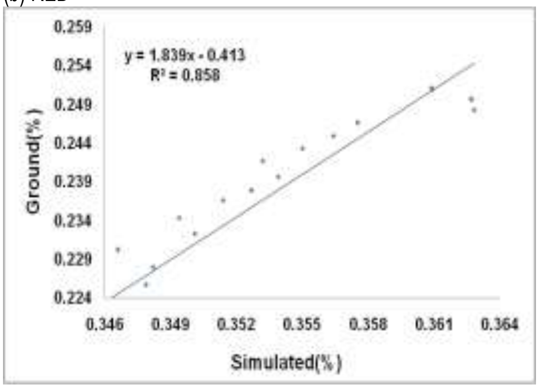
The MODIS 15/03/2016 date simulated and ground were validated with in situ observation collected over a limited area during 2016 wheat seasons. In situ diurnal ground at spectroradiometer and simulated at PROSIAL model were collected as per the sample design give for LAI. For date 15/01/2016 and best band is red band (R2 = 0.95, n=13) and SWIR band (R2 = 0.95, n = 31) lowest R2 values is NIR band (R2=0.78, n= 19).



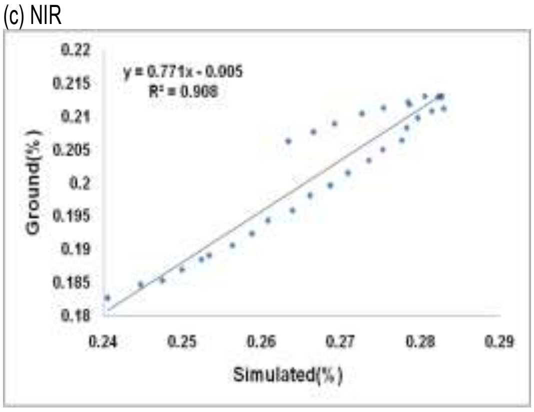
(a) GREEN



(b) RED



(c) NIR



(d) SWIR

Fig-9 Relationship between Ground Reflectance and Simulated Reflectance on 15.03.16

Conclusion

The spatial resolution of AWiFS (56m) was found adequate enough to ensure relatively accurate retrials of LAI of wheat crop at regional scale. The AWiFS has a 5- days revisit period which may cause loss of data due to persistent cloud or fog and to assess. However, the Resouresat-2 increases the possibility to get clear sky data availability. The linear correlation between simulated and ground data during the wheat growing season gave high coefficient of determination (R2= 0.99) in SWIR band.

Application of Research: This study is very helpful for forecasting crop coverage area for the whole region as well as forecasting of major crop diseases and their control in time. It is also helpful in forecasting of crop yield of the entire region and its subsequent management.

Research Category: Crop Science

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Research project name or number: Research station trials

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Study area / Sample Collection: Halali of district Raisen

Cultivar / Variety name: Wheat

Conflict of Interest: None declared
Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

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