Predicting yield of *Lahi* (*Brassica campestris* var. toria) crop using remote sensing in *Tarai* region of Uttarakhand

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सार - यह शोध लाही (ब्रेसिका कैम्पिस्ट्रस प्रजाति तोरई) की फसल के पूर्वानुमान के लिए विकसित किए गए स्पैक्ट्रो- मौसम विज्ञानिक मॉडलों के माध्यम से उत्तराखंड राज्य में वर्ष 2009-10 में रबी के मौसम के दौरान किया गया। इस अध्ययन के लिए वर्ष 2004-05 से 2008-09 के पाथ 145 तथा रो 40 (पंतनगर और उसके आस-पास के क्षेत्र के) के लाही की फसल के फसल प्रबंधन तथा मेघ मुक्त LANDSAT – ETM + प्रतिबिम्बों का उपयोग किया गया। कुछ महत्पूर्ण फसलों की घटना वैज्ञानिक अवस्थाओं से संबंधित NDVI और मौसम विज्ञानिक आँकड़ों का उपयोग करके स्पैक्ट्रो मौसम विज्ञानिक मॉडलों का विकास किया गया है। सामान्य वृद्धि वक्र से NDVI में विचलन के संयोजन और फसल की वृद्धि की विभिन्न अवस्थाओं में साप्ताहिक मौसम परिवर्तिता का उपयोग करके लाही की फसल के लिए आठ स्पैक्ट्रो मौसम विज्ञानिक मॉडल विकसित किए गए। इन मॉडलों से उपज और मौसम/स्पैक्ट्रल प्राचलों के बीच संबंध का पता चला। प्रेक्षित उपज 9.65 q ha^{-1} से 20.67 q ha^{-1} तक रही तथा इन आठ मॉडलों से पूर्वानुमानित उपज 9.70 q ha^{-1} से 21.07 q ha^{-1} तक रही।

मॉडल 8 द्वारा निर्धारक गुणांक के अधिकतम मान (R^2 = 0.977) से पता चला कि स्थान विशिष्ट स्पैक्ट्रो मौसम विज्ञानिक मॉडलों का विकास करने के लिए मौसम प्राचलों के संयोजन के साथ NDVI का उपयोग किया जा सकता है, जो फसल की कटाई से पहले उपज का बेहतर पूर्वानुमान उपलब्ध करा सकता है।

ABSTRACT. Present study was conducted in Uttarakhand state during *rabi* season for the year 2009-10 in which spectro-meteorological models were developed for predicting the yield of *Lahi* (*Brassica campestris* var. toria) crop. Crop management data for *Lahi* crop and cloud free LANDSAT-ETM+ images of path 145 and row 40 (containing Pantnagar and adjoining region) of the year 2004-05 to 2008-09 were used for the study. Spectro-meteorological models have been developed using NDVI and meteorological data pertaining to some significant crop phenological stages. Eight spectro-meteorological models were developed for *Lahi* crop using combinations of deviations in NDVI from normal growth curve and weekly weather variables at different crop growth stages. These models expressed the relationship between yield and weather/spectral parameters. The observed yield ranged from 9.65 q ha^{-1} to 20.67 q ha^{-1} and the yield predicted by these 8 models varied from 9.70 q ha^{-1} to 21.07 q ha^{-1}.

The highest value of co-efficient of determination (R^2 = 0.977) by model 8 shows that NDVI in combination with weather parameters can be used to develop location specific spectro-meteorological models, which can provide better pre-harvest yield forecast.

Key words – Vegetation index, LANDSAT-ETM + images and correlation with weather parameters.

1. Introduction

Lahi (*Brassica campestris* var. toria) is grown in the *Tarai* region of Uttarakhand as a winter crop from September end to mid October and harvesting starts from mid December to end of December. The crop duration is 80-90 days and active vegetative phase continues for the first 35-45 days of growth cycle and attains maximum flowering stage at around 40 days. Weather variables like, temperature (maximum and minimum), rainfall, bright sunshine hours, relative humidity etc. are used as indicators in the development of empirical statistical models using multiple linear regression techniques (Saha, 1999; Vyas *et al.*, 1999). Remote sensing provides timely information about the crop condition and its yield (Bauer, 1975; Brach *et al.*, 1977). Remote sensing products have been used in different parts of the world to estimate crop yield (Hochheim and Barber, 1998; Lewis *et al.*, 1998; Wang *et al.*, 2005). Pre-harvest yield prediction may help the planners in deciding policy on food management. The
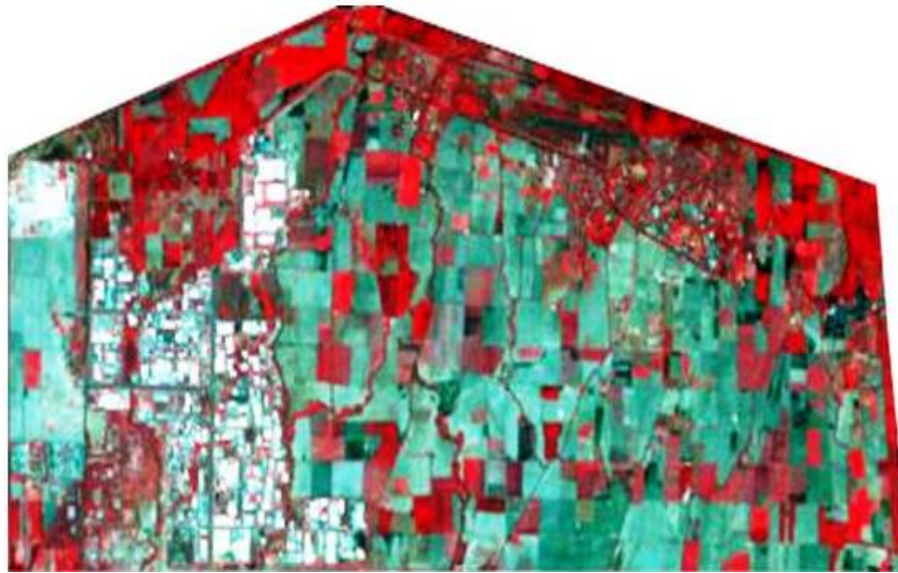
Fig. 1. A sample of subset image of Agricultural Farm G.B.P.U.A.&T., Pantnagar

purpose of this investigation is to improve the spatial estimation of yield of *Lahi* crop by combining weather parameters and satellite observations.

2.   Data and methodology

2.1. *Study area*

Field study was conducted at Agricultural Farm of G. B. Pant University of Agriculture and Technology, Pantnagar for predicting the yield of *Lahi* (*Brassica campestris* var. toria) crop during the *rabi* season of the year 2009-2010. Geographically, this centre is situated at 29° N latitude and 79.3° E longitude, 216 amsl. The area lies in the ''*Tarai*'' belt located in foot hills of the Himalayas.

2.2. *Software used*

Two softwares namely ENVI-4.8 (Environment for Visualising Images) and SPSS were used for this study. ENVI-4.8 was used for processing the remote sensing images and SPSS software was used for the statistical analysis and to develop spectro-meteorological yield models based on deviation of mean NDVI from normal growth curve and weather variables. With the help of SPSS software, R^2, F-value, standard error, etc. were calculated.

2.3. *Collection of weather data*

The daily weather data used in the study as indicators in crop yield prediction were collected for 5 crop seasons (September to December) during 2004-05 to

2008-09 from the Agrometeorological observatory located at Norman E. Borlaug Crop Research Centre (NEB-CRC), G. B. Pant University of Agriculture and Technology, Pantnagar.

2.4. *Collection of plant and management* data

Plant and management data (Sowing/harvesting date, irrigation scheduling etc.) related to the *Lahi* crop for the above period were collected from Agriculture Farm of G. B. Pant University of Agriculture and Technology, Pantnagar. Plot size of area more than 3 ha was selected, so that it could be captured by remote sensing technique. A total of 13 farmers' fields during 2004-05 to 2008-09 were also included for the analysis.

2.5. *Remote sensing images*

Cloud free crop seasons LANDSAT-ETM+ reflective images for a period of 5 years (2004-05 to 2008-09) of path 145 and row 40 (Containing Pantnagar and adjoining region) were used to derive NDVI. All the visible and infrared bands of 30 m resolution (LANDSAT-ETM + bands 1 to 5 & 7), except the thermal infrared and panchromatic (bands 6 and 8) were included in the analysis. In addition selected image transforms (vegetation indices) were produced for analysis. All layers are available in standardized unsigned 8-bit (256 range) data type. The data are being currently provided by USGS at their website for download (http://Edcsns17.cr.usgs. gov/EarthExplorer/). The present LANDSAT-ETM+ were available in SLC (Scan Line Corrector) off mode, which have horizontal blank strips from center broadening towards the East and West of the images. However,
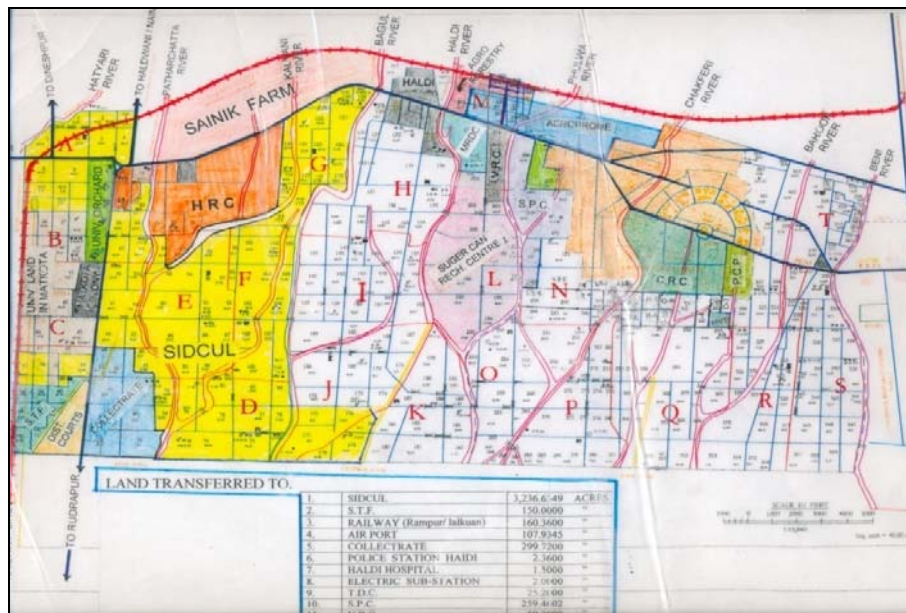
Fig. 2. The unscaled map of the Agriculture farm of the G.B.P.U.A. & T., Pantnagar

centered 22 km strip in the images is considered free from any error. Pantnagar having Agricultural Farm is located in the middle stripless area of the image. Therefore, Pantnagar region was subset from each image for further analysis (Fig. 1).

2.6. *Field boundary digitization*

The field boundaries of different plots of the Agriculture farm (Block H and I) were digitized. These were not clearly discernable in the LANDSAT-ETM+ reflective images as the spatial resolution is 30×30 m and there is a mixing of crops. Therefore, the high resolution images available on Google-Earth were used to identify the boundary of individual fields. Overall 4 tiles of size 4.02 km × 4.02 km were acquired from the website earth.google.com to cover the entire region of Agriculture farm. The satellite collects panchromatic (black and white) imagery at 60 cm resolution and multispectral imagery at 2.4-2.8 meter resolutions. The multispectral product available on Google earth has been sharpened and resampled to 60 cm. The pixel based mosaicking was applied for all the tiles which involve identifying the overlapped areas and placing all the tiles at right places. After mosaicking of all tiles image to image geo-referencing was performed with the help of ENVI-4.8 software. The LANDSAT-ETM+ reflective image of 30 meter was considered as master image (base image) for registering the Google-Earth mosaicked image. Different feature objects such as road, river, field boundary etc. were identified in the Google-Earth image with the help of

unscaled published map (Fig. 2) of the University farm and digitization was done with the help of ENVI-4.8 software.

2.7. *Generation of growth profile*

Crop growth profile was generated using field measurements and LANDSAT-ETM data. NDVI which is widely accepted index for vegetation analysis was considered to represent the growth of crop. Field boundaries generated were overlaid on each of the registered NDVI images. The average NDVI values of selected fields were extracted using ENVI-4.8 image processing software. In order to construct the growth profile, a year having maximum number of images during crop season has been selected. In the year 2007-08, the number of cloud free images was five. Plot no.135 which was the representative field of healthy *Lahi* crop has been selected for the study. The field boundary of plot no. 135 was extracted from the vector file (containing boundary of block H and I) of the farm and accordingly the field was masked.

2.8. *Development of spectro-meteorological yield models*

Meteorological parameters during important stages of crop were used for the development of multiple variable regression models in combination with deviations in NDVI from the normal growth curve. Average NDVIs of selected farm field were calculated through

band math module of the ENVI-4.8 image processing software and followed by masking the field by overlaying the ROIs (Region of Interest) using overlay option of ENVI-4.8. The daily weather data of important crop growth stages (25-30 days after sowing of *Lahi* crop) so collected were converted into the weekly weather data by taking average of all parameters except for rainfall which was summed up for entire week (end of November to 1st fortnight of December). These weekly weather data and NDVI deviation were incorporated in SPSS software for the development of "spectro-meteorological models". The development of "spectro-meteorological models" employs that the dependent variable (yield) of multiyear are related with the independent spectral (NDVI) and weather variables. NDVI, which is measurement of vigour of crop plant, was calculated using following equation (Rouse *et al.*, 1974):

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

where, NIR and RED are the reflectance or radiances in the near-infrared and red spectral channels, respectively.

The deviations in NDVI were calculated with reference to the normal growth profile of *Lahi* at Pantnagar region. The deviations of each field were calculated as follows:

$$NDVI_{deviation} = \frac{NDVI - NDVI_{normal}}{NDVI + NDVI_{normal}} \times 100$$

where, $NDVI_{deviation}$ = Deviation in NDVI from the normal values of NDVI at a specified time after sowing; $NDVI_{normal}$ = The expected values of NDVI at a specified time after sowing based on historical values of NDVIs.

Multiple regression models were developed with the help of SPSS software by using different sets of independent variables. The forward stepwise parameter selection approach was used with describing f range criteria. An example of multiple regression equation is given below.

$$Y = a + bx_1 + cx_2 + dx_3 + \ldots.$$

where,

Y   = Yield (q/ha)
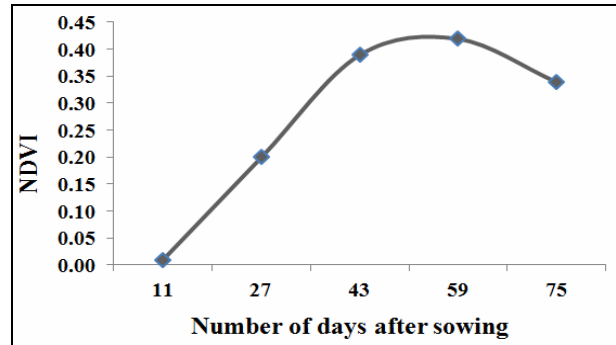
A   = Multiple regression constant

Fig 3. Temporal behaviour of spectral response of the *Lahi* crop in two bands
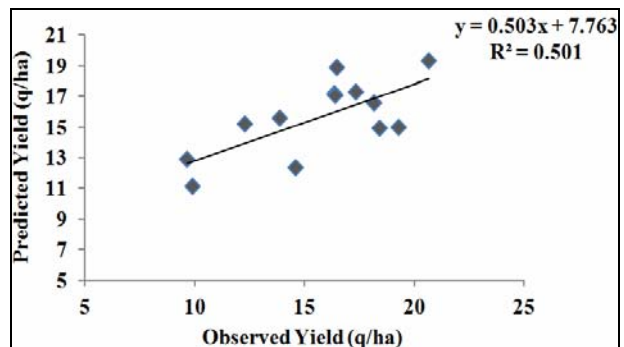

Fig. 4. Comparison between observed and predicted yield (Model-1)
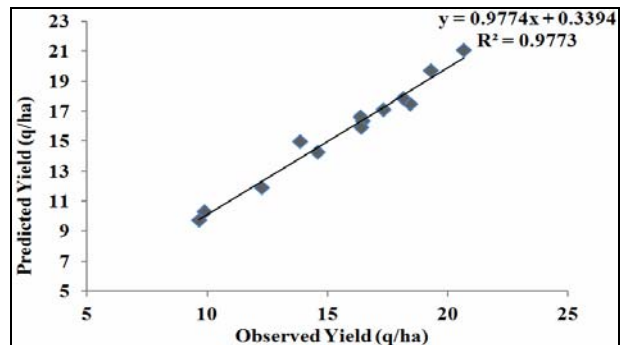

Fig. 5. Comparison between observed and predicted yield: (Model-8)

b, c, d...   = Slope of the curve

$x_1, x_2, x_3\ldots$ = Relative deviation percentage, average weekly weather parameters etc.

2.9. *Yield prediction and accuracy analysis*

The operational viability of remote sensing based "spectro-meteorological model" largely depends upon the accuracy of the model to perform the yield prediction task

TABLE 1

Spectro-meteorological yield models of *Lahi* crop based on the weekly weather data

Model No.	Spectro-meteorological model equation	R^2
1.	$Y = 16.82+0.11*(x_1)$	0.501
2.	$Y = -3.631+0.141*(x_1)+1.249*(x_2)$	0.650
3.	$Y = -14.795+0.141*(x_2)+1.302*(x_2)+0.673*(x_3)$	0.729
4.	$Y = -13.122+0.168*(x_1)+1.258*(x_2)+0.946*(x_3)+(-0.752)*(x_4)$	0.803
5.	$Y = -24.705+0.218*(x_1)+1.043*(x_2)+1.669*(x_3)+(-2.183)*(x_4) + 7.565*(x_5)$	0.895
6.	$Y = -5.436+0.223*(x_1)+1.161*(x_2)+2.134*(x_3)+(-2.74)*(x_4)+ 6.523*(x_5)+ (-.341)*(x_6)$	0.916
7.	$Y = 14.932+0.215*(x_1)+1.435*(x_2)+2.123*(x_3)+(-3.989)*(x_4)+ 6.578*(x_5)+(-1.016)*(x_6) +0.404*(x_7)$	0.957
8.	$Y = 4.554+0.089*(x_1)+0.932*(x_2)+0.348*(x_3)+(-4.999)*(x_4)+ 17.526*(x_5)+(-0.921)*(x_6) +0.829*(x_7)+(-1.679)*(x_8)$	0.977

Where, Y = Yield (q ha^{-1}), X_1 = deviation in NDVI from normal growth curve, X_2 = Average temperature of 2nd week, X_3 = Average temperature of 3rd week and X_4 = Average Bright Sunshine Hours (BSS) of 2nd week, X_5 =Average evaporation of 2nd week, X_6 = Average Relative Humidity (RH) of 2nd week, X_7 = Average RH of 4th week and X_8 = Average wind speed of 2nd week.

accurately. To check the performance of the developed "spectro-meteorological model", the yields of different farmers' fields/plots (total 13 fields of area 3 to 14 ha) for five years (2004-05 to 2008-09) were predicted and compared with the observed values. Co-efficient of determination was used to show the relationships between dependent and independent variables. Model performance was evaluated by calculating Root Mean Square Error (RMSE).

3. Results and discussion

3.1. *Development of normal growth profile for model development*

The NDVI values have gradually increased up to 45-55 days from the date of sowing. When the plant reached flowering stage, NDVI was almost constant and thereafter a decreasing trend was observed as plant reached its maturity stage (Fig. 3).

3.2. *Spectro-meteorological yield models for Lahi crop*

Eight regression models were developed through different combinations of deviation in NDVI from normal growth curve and weekly weather variables at different growth stages for predicting yield of *Lahi* crop at farmer's field level. Abbate *et al.*, 2004 also developed spectro-meteorological model for wheat yield prediction in Argentina. A list of 8 different models with their coefficient of determination has been given in Table 1. The first model (CD = 0.501) only used remote sensing based deviations in NDVI from the normal growth curve to predict the yield underlying the importance of the remote sensing based derived indices.

The model-4 incorporating average bright sunshine hours of second week from the date of flowering improved CD value significantly from 0.729 to 0.803. The average evaporation of the 2nd week after the date of flowering was included in model-5 and the value of R^2 further increased to 0.895. Including average relative humidity of second week after flowering model-6 increased R^2 to 0.916. Model-7 incorporating average relative humidity of 4th week from the date of flowering improved CD value to 0.957. The addition of average wind speed of 2nd week after flowering raised the value of coefficient of determination to 0.977 in case of model-8.

3.3. *Performance of different models in yield prediction of Lahi*

Observed and predicted yield of *Lahi* crop by model-1 has been depicted in Fig. 4. The observed yield ranged from 9.65 q ha^{-1} to 20.67 q ha^{-1} and yield predicted by model-1 ranged from 11.15 qha^{-1} to 19.32 q ha^{-1}, respectively. The RMSE was 14.90% with F value 11.07 significant at 1 per cent level. The value of co-efficient of determination (R^2 = 0.501) reflects the difference in observed and predicted yield by model-1. As the remote sensing derived index only accounts for the vegetative part up to the maximum growth stage, the changes occurring later due to the prevailing meteorological conditions are not reflected.

The range of predicted yield of *Lahi* by model-2 varied from 9.34 q ha^{-1} to 20.73 q ha^{-1}. The better performance of model-2 might be attributed to the inclusion of average temperature of 2nd week. The temperature not only influences photosynthesis rate but also the loss of dry matter in terms of respiration.

The predicted yield by model-5 varied from 10.63 q ha^{-1} to 21.88 q ha^{-1} with RMSE 6.82% and F value 12.04, significant at 1 per cent level. R^2 value 0.895 shows the improved performance by model-5. The reason may be attributed to the inclusion of the weather variable *viz.*, average evaporation of 2nd week from flowering in the model.

Predicted yield by model-8 (Fig. 5) varied from 9.70 q ha^{-1} to 21.07 q ha^{-1}. The RMSE between observed and predicted yield by model-8 was 3.18% and F value was 21.50, which is significant at 1 per cent level. Co-efficient of determination (R^2 = 0.977) shows that performance of model-8 (inclusion of average wind speed of 2nd week after flowering) is better in comparison to rest of the 7 models. Similar results were produced by Bazgeer *et al.,* 2006 and Ranjan *et al.*, 2012.

4.   Conclusion

A total number of 8 spectro-meteorological yield models were developed and validated by comparing the predicted block level yields of *Lahi* crop with those estimated by observed data.

Preceding results show that NDVI in combination with weather parameters can be used to develop location specific "spectro-meteorological model" which will provide pre-harvest yield forecast quite reasonably (Verma *et al.*, 2003).

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