Semi Physical Approach for Sugarcane Yield Modelling with Remotely Sensed Inputs

G. Chaurasiya, Shalini Saxena*, Rojalin Tripathy[**], K. N. Chaudhari [**] and S. S. Ray*
Remote Sensing Applications Centre, Lucknow
**Mahalanobis National Crop Forecast Centre*
DAC&FW, Pusa Campus, New Delhi
[**]Space Applications Centre, ISRO, Ahmedabad
Email: shalini.85@gov.in

ABSTRACT

Sugarcane, being a cash crop, its yield forecasting is essential for making various agricultural decisions related to price, storage, export/import etc. Hence, the present study was carried out to estimate yield of sugarcane crop using remote sensing technology. This study developed an intermediate method based on the use of remote sensing and the physiological concepts such as the photo-synthetically active radiation (PAR) and the fraction of PAR absorbed by the crop (fAPAR) in Monteith's radiation use efficiency equation). Net Primary Productivity (NPP) has been computed using the Monteith model and moisture stress has been applied to convert the potential NPP to actual NPP. Sugarcane yield was calculated using the NPP, harvest index and radiation use efficiency. Net Primary Productivity was assessed during the sugarcane crop season of 2015-16. Water stress scalar showed values ranged between 0.01 to 0.2 (Maximum stress) in Bahraich, Saharanpur, Meerut and Muzaffarnagar in the month of April and May as compare to the central and eastern part of Uttar Pradesh. APAR was found higher in western Uttar Pradesh ranged from 35.0 to 73.6 MJ/m^2 which gradually decreased in the month of July which ranged between 25.0 - 75.2 MJ/m^2. During crop season maximum yield was found between 50-60 t/ha for most of the western districts of Uttar Pradesh.

Keywords: *Remote Sensing, Monteith equation, LSWI, KVHRR & Spectral yield*

1. Introduction

Sugarcane is one of the crops assessed under the FASAL (Forecasting Agricultural output using Space, Agro-meteorology and Land based observations) project of Department of Agriculture, Cooperation & Farmers' Welfare, Government of India (Ray, et al., 2014). Currently, the crop yield estimates are generated using meteorological (Tripathy et al., 2012) or remote sensing (Dubey et al., 2016) based empirical models. However, in order to improve the accuracy of the yield estimation, there is need to explore the use of semi-physical remote sensing models, which has been explored for crops like wheat and mustard, in India (Tripathy et al., 2014). The current study was carried out in this context.

Sugarcane is cultivated in the tropical and subtropical regions of the world. India has the largest area under sugarcane cultivation in the world and it is the world's second largest producer of sugarcane next only to Brazil. India is the original home of Saccharum species, *Saccharum barberi* and Polynesian group of island especially New Guinea is the centre of origin of S. *officinarum.* It belongs to family gramineae (poaceae). Sugarcane is a tall perennial plant growing erect even up to 5 or 6 metres and produces multiple stems. The plant is composed of four principal parts, root system, stalk, leaves and inflorescence. The sugarcane cultivation and sugar industry in India plays a vital role towards socio-economic development in the rural areas by mobilizing rural resources and generating higher income and employment opportunities.

It is a long duration crop and requires 10 to 15 and even 18 months to mature, depending upon the geographical conditions. It requires hot and humid climate with average temperature of 21°-27°C and 75-150 cm rainfall. Sugarcane take generally one year to mature in sub tropical states (U.P., Punjab, Haryana, Bihar etc.) called “Eksali” however in some tropical states it matures in 18 months (Andhra Pradesh, Karnataka, Maharashtra etc.) called “Adsali”. In India planting seasons of sugarcane in subtropical regions are September to October (Autumn) and February to March (spring), whereas in tropical regions it is June to August (Adsali) and January to February and October to November (Eksali). Apart from this in some states like Karnataka and Tamil Nadu sugarcane planting continue throughout the year except few months.

Remote sensing techniques can play quite an important role in agriculture monitoring and as a source of information relating to land resource condition. Remote sensing data are capable of capturing changes in plant phenology throughout the growing season, whether relating to changes in chlorophyll content or structural changes. Satellite and airborne images are used as mapping tools to classify crops, examine their health and viability, and monitor farming practices. Spectral reflectance indices which are formulated based on simple operation between the reflectance at given wavelengths, are mainly used in the assessment of plant characteristics related to the photosynthetic area of the canopy. To utilize the full potential of remote sensing for the assessment of crop condition and yield prediction, it is essential to quantify the relationships between agronomic parameters and the spectral properties of the crop.

The amount of electro-magnetic radiation (EMR) reflected from a crops canopy is positively correlated to the leaf area index, which in turn may correspond to the amount of biomass within the crop, and therefore yield (Begue *et al*., 2010). This relationship can be influenced by variations in canopy architecture, foliar chemistry, agronomic parameters and sensor and atmospheric conditions (Abdel-Rahman and Ahmed, 2008). More specifically, variety, crop class (plant or ratoon), date of crop planting or ratooning, duration of harvest period and environmental variability are all factors that have been shown to influence the accuracies of yield prediction algorithms developed from remotely sensed imagery (Zhou *et al.,* 2003; Inman-Bamber, 1994).

PAR (0.4–0.7 µm) is a fraction of the incoming solar radiation. Although the PAR fraction varies with visibility, optical depth and ozone amount, among others (Frouin and Pinker, 1995), a value of approximately 45–50% is generally accepted to represent the 24 h average conditions (Moran *et al*., 1995). The PAR value describes the total amount of radiation available for photosynthesis if leaves intercept all radiation. This is a rather theoretical value because leaves transmit and reflect solar radiation. Only a fraction of PAR will be absorbed by the canopy (APAR) and used for carbon dioxide assimilation. The spectral observation for developed vegetation indices in these wavelengths have correlated highly with plant stand parameters, green leaf area index (L), chlorophyll content, fresh and dry above ground phytomass, plant height, present ground cover by vegetation, plant population and grain or forage yield (Wiegand et al., 1991). Moulin and his co-author’s in 1998, has proposed that combining crop model and remotely sensed information is a promising approach to overcome some of the mentioned limitations especially at regional scales.

The Net Primary Productivity (NPP) is estimated applying the efficiency model as proposed by Kumar and Monteith (1982). The model linearly relates the NPP to the photo-synthetically active radiation (PAR) absorbed by vegetation (APAR) and the plant radiation use efficiency (RUE) which is the energy conversion coefficient of absorbed radiation into aboveground biomass. APAR can be calculated by multiplying the fraction of PAR intercepted by vegetation (fPAR) by the incoming PAR. Three approaches are commonly used to model the growth and development of plant canopies and phytomass during a growing season. The first approach uses mechanistic models of the plant photosynthetic system, which have been reviewed by Thornley and Johnson (1990). The second approach is based on the empirical model of Monteith (1977), who showed that a simple model of phytomass production predicted a relationship between plant growth and intercepted solar radiation. Values of the radiation use efficiency of a canopy are usually determined from the slope of the regression between accumulated solar or absorbed photo-synthetically active radiation (APAR) in MJ d^{-1}. The third approach uses spectral remote sensing to obtain indirect estimates of the fraction of APAR from the reflectance characteristics of plant canopies in the red and infra-red (Goudriaan, 1977; Kumar and Monteith, 1982; Christensen and Goudriaan, 1993). The empirical model of Monteith (1977) has been widely used to establish a linear relationship between the accumulation of carbon and the accumulation of absorbed photo-synthetically active radiation (PAR)-(APAR) by plant canopies. The present study carried out with the objective to estimate the yield of sugarcane crop using Monteith approach (semi-physical approach).

2. Material and Methods

2.1. Study area

Study area comprises seventy five district of Uttar Pradesh (Fig1). Western U.P contributes to 34 percent of total food grain production at state level and 6 percent at national level. Sugarcane and wheat is the dominant crop of western region Uttar Pradesh.

The study area is bound by Nepal on the North, Himachal Pradesh on the northwest, and Haryana on the west, and Rajasthan on the southwest, Madhya Pradesh on the south and south- west and Bihar on the east. Uttar Pradesh Situated between 23° 52' N and 31° 28' N latitudes and 77° 30' and 84° 39'E longitudes, this is the fourth largest state in the country. The major sugarcane growing district of Uttar Pradesh i.e. Saharanpur, Muzaffarnagar, Meerut, Bulandsahar, Baghpat, Bareilly, Moradabad, Rampur, Lakhimpur Kheri, Sitapur, Gonda, Basti, Balrampur and Kushinagar.

A long, warm growing season with a high incidence of solar radiation and adequate moisture (rainfall) is required for production of maximum sugar from sugarcane. Growth is closely related to temperature. Optimum temperature for sprouting (germination) of stem cuttings is 32° to 38°C and practically stops when the temperature is above 38° C. Temperatures above 38° C reduce the rate of photosynthesis and increase respiration. For ripening, however, relatively low temperatures in the range of 12° C to 14° C are desirable, since this has a noticeable influence on the reduction of vegetative growth rate and enrichment of sucrose in the cane. A well drained, deep, loamy soil is considered ideal for sugarcane cultivation. Other crops in field during sugarcane planting is depend upon the seasons. Like paddy- i) *Autumn* sugarcane-ratoon-wheat ii) Bajra-sugarcane (pre-seasonal)-ratoon- wheat; iii) Greengram- *autumn* sugarcane-ratoon in subtropical regions whereas; iv) *Kharif* crops-potato-*spring* sugarcane-ratoon; v) Wheat paddy-sugarcane-ratoon- gingelly; vi) *Kharif* crops-mustard-*spring* sugarcane-ratoon in tropical regions.

2.2. Data used and their source

The MODIS Terra 8-day spectral reflectance and FAPAR data product from (http://LPDAAC.usgs.gov) starting from the (02 Feb. 2015 to 31 Nov. 2015) was used in the analysis. The data were processed though ERDAS Imagine and ENVI; image processing software to derive the LSWI which was calculated from the NIR and SWIR reflectance. MODIS data possesses seven spectral bands that are specifically designed for land applications with spatial resolutions that range from 250 m to 1 km (Justice et al., 1997). Satellite dataset used for this study was MODIS, MOSDAC, LISS-III. Details are given in Table 1.

2.3 Methodology

The methodology is based on the concept that the biomass produced by a crop is a function of the amount of photo-synthetically active radiation (PAR) absorbed, which is depends on incoming radiation and the crops PAR interception capacity. For this the equation developed by Monteith (1977) to quantify the fAPAR. fAPAR is defined as the fraction of absorbed PAR (APAR) to incident PAR ($0 < fAPAR < 1$). The incident PAR is transformed into dry matter can be written as:

$$NPP = PAR.fAPAR.\varepsilon \quad (1)$$

Where NPP = Net Primary Productivity or dry matter accumulation in plant over a period of time ($gm^{-2}d^{-1}$) ; PAR = Photosynthetically active radiation ($MJm^{-2}d^{-1}$); *fAPAR*= fraction of incident PAR which is intercepted and absorbed by the canopy (dimensionless; $0 < fAPAR < 1$) ; ε = Light-use efficiency of absorbed photosynthetically active radiation (gMJ^{-1}) PAR, fAPAR and the stress factors was computed over the whole sugarcane crop season (Jan 2015 to Dec. 2015) at a temporal resolution of 8 days. The impact of water stress (W_{stress}) and temperature stress (T_{stress}) on photosynthesis has also observed and hence the modified equation becomes

$$NPP = PAR.fAPAR.\varepsilon o.\mathrm{Wstress}.\mathrm{Tstress} \quad (2)$$

2.3.1 Fraction of Absorbed PAR (fAPAR)

Spatial and temporal scales information on PAR is needed for applications dealing with productivity (Running *et al*., 2004). FAPAR varies in space and time due to difference between species and ecosystem, human activities and weather and climate processes (Myneni and Williams, 1994) defined FAPAR as fraction of incident PAR absorbed by photosynthesizing tissue in a canopy fraction of PAR absorbed by vegetation (Chen, 1996; Gower *et al*., 1999); (Tian *et al*., 2000). FAPAR 8-day composite derived from Terra-MODIS sensor. The values of FAPAR have a potential range from 0 (no interception or no absorption) to 1 (total interception or total absorption).

2.3.2 Photo-synthetically Active Radiation (PAR)

Photo-synthetically active radiation (PAR) is a portion of sunlight's spectrum from 400 to 700 nm or 0.4 to 0.7 (μm) which is comparable to the range of light the human eye can see. Absorption of light by chlorophyll takes place largely within narrow bands that peak at 680 nm and 700 nm.

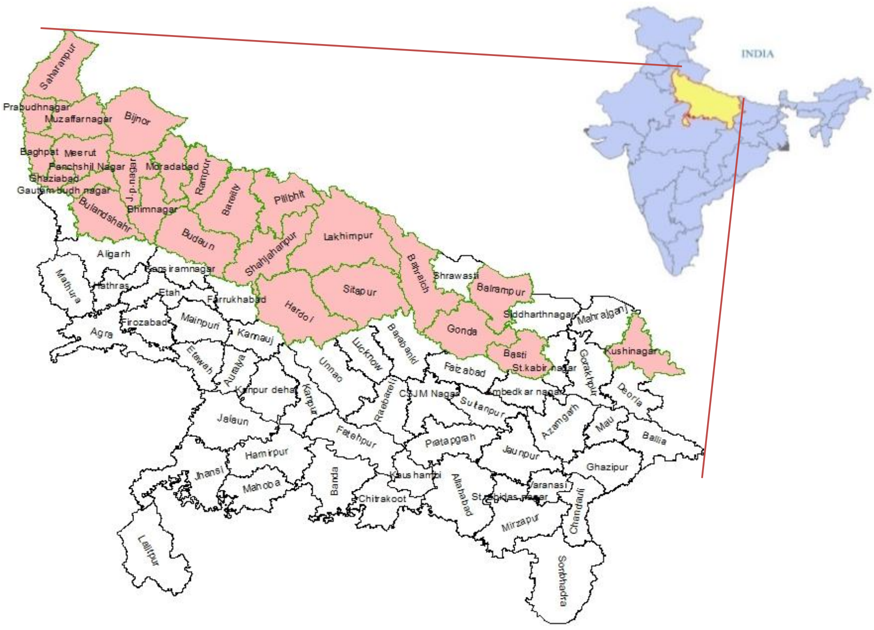

Figure 1: Study Area

Table1. Details of satellite data products used in this Study

Data/Product	Satellite/ Ground	Sensor	Resolution	Source
Daily Insolation	Kalpana-1	VHRR	8 km	MOSDAC
8 - days Composite fAPAR	Terra	MODIS	1 km	LPDAAC@usgs.gov
8-days composite Surface Reflectance	Terra	MODIS	0.5 km	LPDAAC@usgs.gov
Crop Mask	Resourcesat	LISS-III	0.0235 km	MNCFC, Delhi
Daily Tmin and Tmax interpolated map	Ground Station of IMD		0.5 x 0.5 degree	IMD data, SAC
RUEmax and HI				Old review & Literature

Even though green light (~550 nm) is within the PAR region, a greater proportion of it is reflected compared to the other PAR (W/m2) wavelengths.

2.3.3 Land surface water index (LSWI)

LSWI is derived from the NIR and SWIR regions of electromagnetic spectrum for water stress assessment. This index is sensitive for the total amount of vegetation and soil moisture. The equation to calculate LSWI is given in equation 3.

$$\text{LSWI} = \frac{(\text{NIR}-\text{SWIR})}{(\text{NIR}+\text{SWIR})} \qquad (3)$$

Estimated LSWI was further used in calculating water stress scalar (Ws) (Equation 4) (Xiao et al., 2005)

$$\text{W stress} = \frac{(1-\text{LSWI})}{(1+\text{LSWImax})} \qquad (4)$$

Where**,** LSWI is value of particular pixel

LSWImax is spatial maximum of the state on a particular day

2.3.4 Temperature stress

Agro-climatic indices such as Temperature Stress have been used to develop Spectral yield models for sugarcane crop. The Temperature stress is calculated using the equation (Raich JW, Rastetter EB, et.al., 1991)

$$\text{T stress} = \frac{(T-T_{min})(T-T_{max})}{[(T-T_{min})(T-T_{max})-(T-T_{opt})^2]} \qquad (5)$$

Where, T_{min} = Minimum temperature for photosynthesis (°C); T_{max} = Maximum temperature for photosynthesis (°C); T_{opt} = Optimal temperature for photosynthesis (°C); T = Daily mean temperature (°C).

For Sugarcane,
T_{min} = 15°C; T_{max} = 45°C and T_{opt} = 27°C.
If air temperature falls below T_{min}, T_{scalar} is set to be zero. The economic grain yield is the product of harvest index (HI) and net primary productivity (NPP).

8 days NPP integrated from planting date to harvest date which varies with different regions & agro-climatic condition. The sugarcane crop mask is applied to LSWI and APAR to compute the total NPP. The pixel yield was averaged to district level and average state level yield computed.

2.3.5 Satellite data analysis and processing

Multi-temporal LISS-III datasets (Resourcesat-2), MODIS, MOSDAC (KVHRR) were used for analysis. The maximum and minimum temperatures from Automatic Weather Station of IMD were used in the study. ERDAS IMAGINE; ENVI +IDL and ARCGIS software were used for digital data processing, analysis and integration of spatial and non-spatial data,

The MODIS data was geo-referenced and converted the projection and set to Geo Lat/Long (WGS 1984). Sugarcane crop mask was used that had been generated from Resourcesat-2 LISS-III data with 23.5 m resolutions under FASAL Project. Kalpana-VHRR with 8 km and MODIS surface reflectance (MODIS09A1) from Terra sensor was used. Daily average temperature had been computed from the daily maximum and minimum temperature of IMD weather data interpolated to 0.5 x 0.5 km grid.

2.3.6 Processing of MODIS data product

MODIS surface reflectance products 8-day composites with 500m spatial resolution, fAPAR product 8day composites with 1000 m resolution was downloaded from satellite data source link (https://lpdaac.usgs.gov). The product was an estimate of the surface spectral reflectance for each band as it would had been measured at ground level if there were no atmospheric scattering or absorption.

2.3.7 MODIS surface reflectance (MOD09A1)

MOD09A1 or MODIS Surface Reflectance 8-Day (L3 Global 500 m resolution) composite was used. The composite contains seven spectral bands of data. It also has an additional 6 bands of information concerning quality control, solar zenith, view zenith, relative azimuth, surface reflectance 500 m, and surface reflectance day of year with a band width i.e. Band 1: 0.620-0.670 µm; Band 2: 0.841-0.876 µm; Band 3: 0.459-0.479 µm; Band 4: 0.545-0.565 µm; Band 5: 1.230-1.250 µm; Band 6: 1.628-1.652 µm and Band 7: 2.105-2.155 µm.

2.3.8 MODIS fAPAR (MOD15A2)

The MOD15A2 data product contains crop factor data e.g Leaf Area Index (LAI) and (fAPAR) 8-day (Global, 1km spatial resolution) from Terra satellite. MOD09A1 and MOD15A2 data products were acquired over the sugarcane crop season duration from 01 Jan 2015 to 31 Dec. 2015, and processed. The processing of MODIS data included the mosaicking of tiles for India, resizing to India boundary, conversion to geographical projection, cloud pixel elimination (by removing all pixels with value > 1) and resampling of surface reflectance to 1km. LSWI was calculated using the band 2 (NIR-0.841-0.876µm) and 6 (SWIR1: 1.628-1.652 µm), water stress is computed at 1 km spatial resolution using water stress equations.

2.3.9 Kalpana-VHRR insolation product:

Daily Insolation data product was downloaded from MOSDAC data source link (www.mosdac.gov.in) over the crop season i.e., from 01 Jan 2015 to 30 Nov. 2015, with 8 km spatial resolution. The processing of daily insolation involved the conversion of daily insolation to 8 day product (Sum) and resampling to 1 km resolution. 50 % of the total insolation was assumed as photo-synthetically active radiation (PAR).

2.3.10 Sugarcane crop mask

Sugarcane crop mask (image of sugarcane cropped area) was generated by classifying single-date LISS III data of October/November period, with the support of field observations. For this study crop mask was taken from the FASAL project of MNCFC.

2.3.11 Radiation use efficiency and harvest index

The radiation use efficiency represents the capacity of the plant to convert radiation into dry biomass. A value of 3.22 $g \cdot MJ^{-1}$ as estimated by (Robertson et al. 1996) for sugarcane was used in study and this value was comparable to the value measured by (Martiné, J.F. 2003).

The term “harvest index” is used in agriculture to quantify the yield of a crop species versus the total amount of biomass that has been produced. The commercial yield can be grain, tuber or fruit. The harvest index ranges from 0.6 to 0.8 for sugarcane stalk and 0.06 to 0.10 for sugar yield (Thangavelu S., 2006) and Harvest index for sugarcane yield was found to vary between 66–81% for the commercial hybrids (Kapur Raman, Duttamajumder S. K. *et al.*, 2013). A value 0.8 has been taken as harvest index for sugarcane in this study.

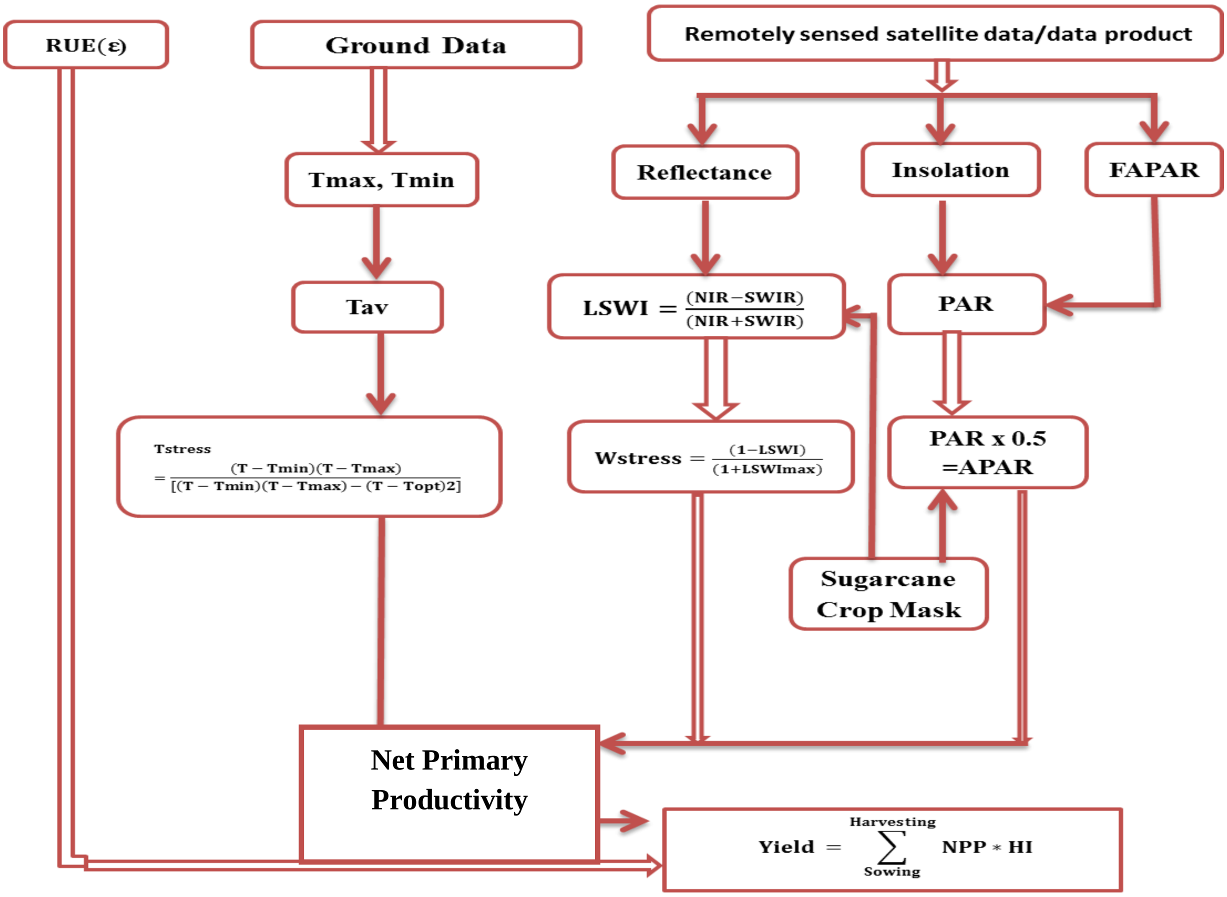

Figure 2. Flow Chart of Methodology adopted for yield estimation of Sugarcane Crop

2.3.12 Validation

The yield estimates from this model were evaluated by comparing the estimated sugarcane yield with the district wise Directorate of Economic and Statistics (DES) data (average of three years).

3. Results

Sugarcane yield was computed for period of sowing to harvest at an internal of 8 days from February 2, 2015 to November, 30, 2015 which was considered as sugarcane crop season. Although in some part of Uttar Pradesh there was slight variation in sowing and harvesting time. But it was found that in most of the part (western to eastern belt) of Uttar Pradesh, the crop was sown during the month of February and March and the peak time for vegetative growth is monsoon season (July to September) where moisture was in adequate amount in the soil. But excess of moisture in the soil is also not favourable for the growth of sugarcane (Source:http://farmer.gov.in/imagedefault/pestand diseasescrops/sugarcane.pdf). Sugarcane starts to harvest in major part of Uttar Pradesh during October end to November. So the stalk yield was computed and compared at district level. The water stress was applied to whole crop season to observe the pattern of growth at each stage. Among the districts, maximum water stress was observed from February, 2015 to November, 2015, with the average values of W_s being 0.53 - 0.61, in all the study districts.

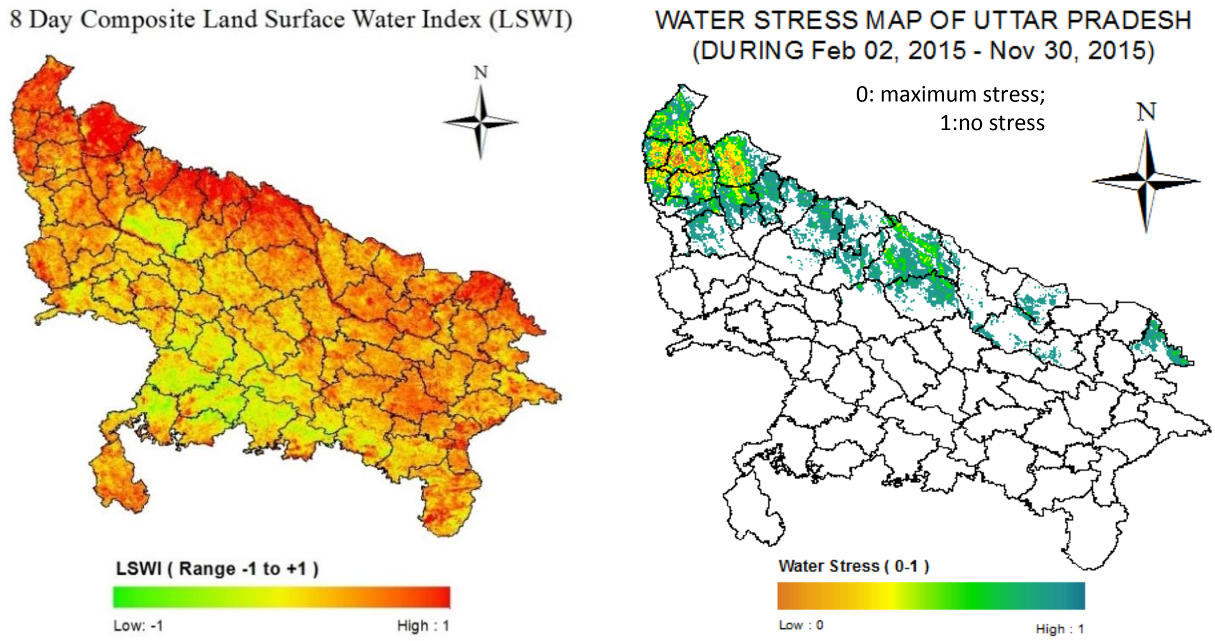

Figure 3: LSWI and Water Stress map for Uttar Pradesh during February, 2015 to November, 2015.

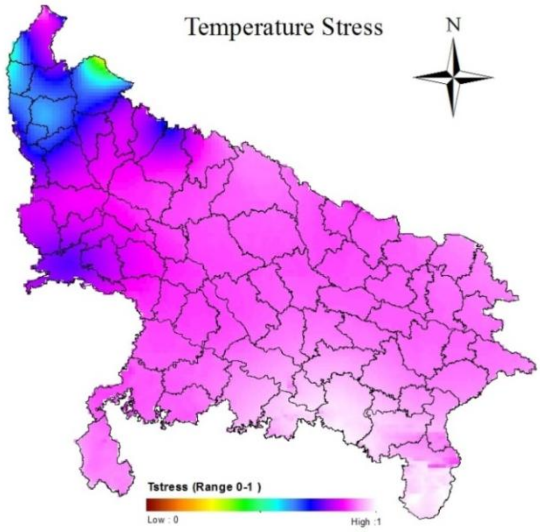

Figure 4. Temperature stress scalar map for Uttar Pradesh state

As per results observed during February, 2015 to November, 2015 in most of the districts, higher values of LSWI were observed. In western Uttar Pradesh LSWI value ranged between 0.2 - 0.5 in the month of February and March. A decrease of trend can be seen where water stress values reaching 0.01 to 0.1 in the month of September and October which showed maximum stress in these region, which gradually shifted towards western Uttar Pradesh, ranged from 0.2 to 0.3 mainly in Bulandshahr, Rampur, Saharanpur, Budaun, Shahjahanpur and Moradabad on the basis of LSWI values, water stress scalar obtained as 1 in Saharanpur, Muzaffarnagar, Meerut, Pilibhit, Rampur, Lakimpur Kheri and Sitapur district, which showed the "No" water stress condition. Water stress scalar showed values ranged between 0.01 to 0.2 (Maximum stress) in Bahraich, Saharanpur, Meerut and Muzaffarnagar in the month of April and May as compare to the central and eastern part of Uttar Pradesh. Water stress was observed between 0.7 to 1.0 (No stress) during June in Saharanpur, Muzaffarnagar, Bijnor, Meerut, Lakhimpur kheri, Sitapur and Bahraich as compare to the eastern Uttar Pradesh which gradually shifted towards central and eastern Uttar Pradesh during July and August. During south west monsoon season (June to August) a higher range of LSWI was found in most of the district of Uttar Pradesh and "No water stress" condition reached in most of the districts in Uttar Pradesh due to rainfall.

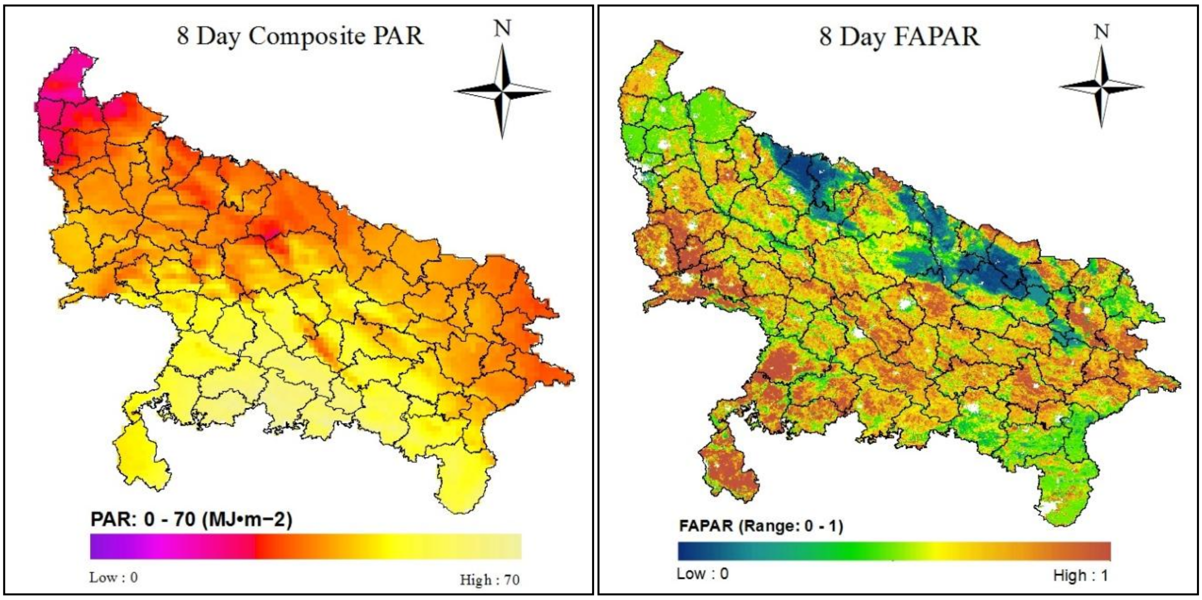

Figure 5. 8-Day composite PAR and FAPAR maps Of Uttar Pradesh State.

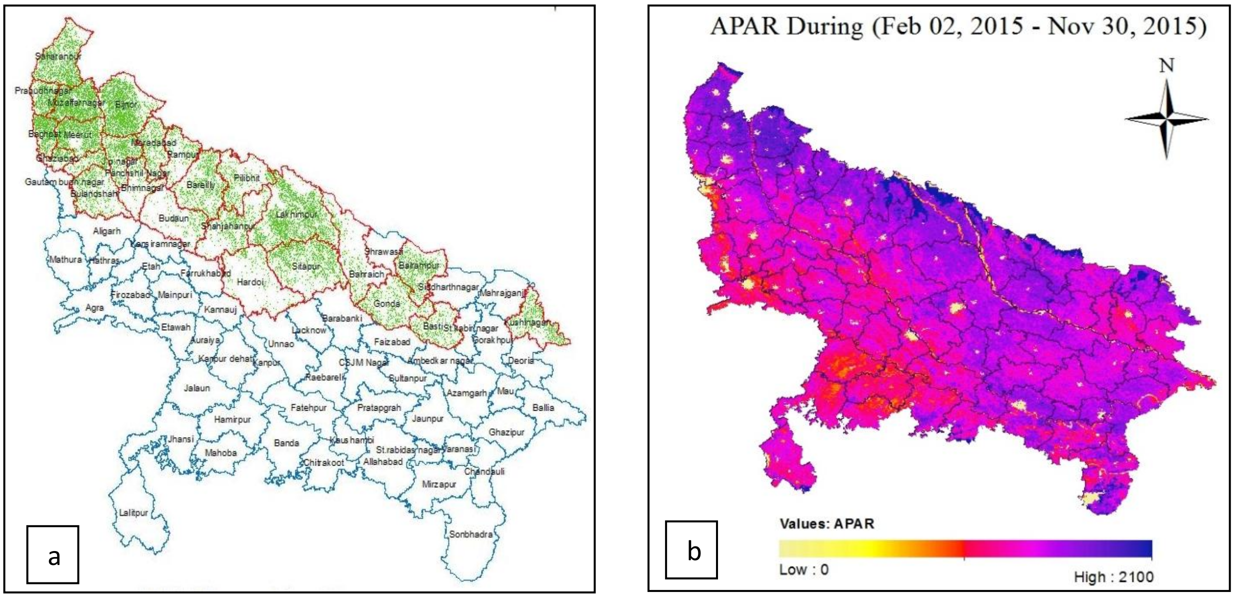

Figure 6 (a) .Sugarcane Crop Mask and (b) sum of APAR (Feb 2015 to Nov 2015)

In the month of February, APAR was found as 23.0 – 35.0 MJ/m^2 in Budaun, Rampur, Bijnor and Saharanpur of western Uttar Pradesh as compared to the districts eastern part of Uttar Pradesh. In April and May months also, APAR was found higher (35.5 - 69.2 MJ/m^2) in western Uttar Pradesh and some districts of central Uttar Pradesh as compared to eastern part of Uttar Pradesh. In the month of August the APAR was found higher in eastern part of Uttar Pradesh as compared to western region but in the month end, the APAR again showed higher values in western and central region as compared to eastern region (30 - 77.6 MJ/m^2). These months were found to be peak season for sugarcane crop in study district. It also observed that yield was highly affected by the APAR and water stress conditions of the crop. During the month of September sugarcane crop starts to harvest in most of the western region. APAR was observed to be a low range between

25.0-45.0 MJ/m^2 as compared to the eastern region.

Sugarcane crop starts to harvest during the month of October and November. (Source: farmer.gov.in/imagedefault/pestanddiseasescrops/sugarcane.pdf). Absorbed Photo-synthetically Active Radiation was observed lower i.e. 16 - 28 MJ/m^2 in eastern part of Uttar Pradesh as compared to western and central part of Uttar Pradesh.

Yield has been calculated using equation 6.

$$\text{Yield} = \text{APAR} \times \text{Water stress} \times \text{Temperatre stress} \times \text{RUE} \times \text{HI} \quad (6)$$

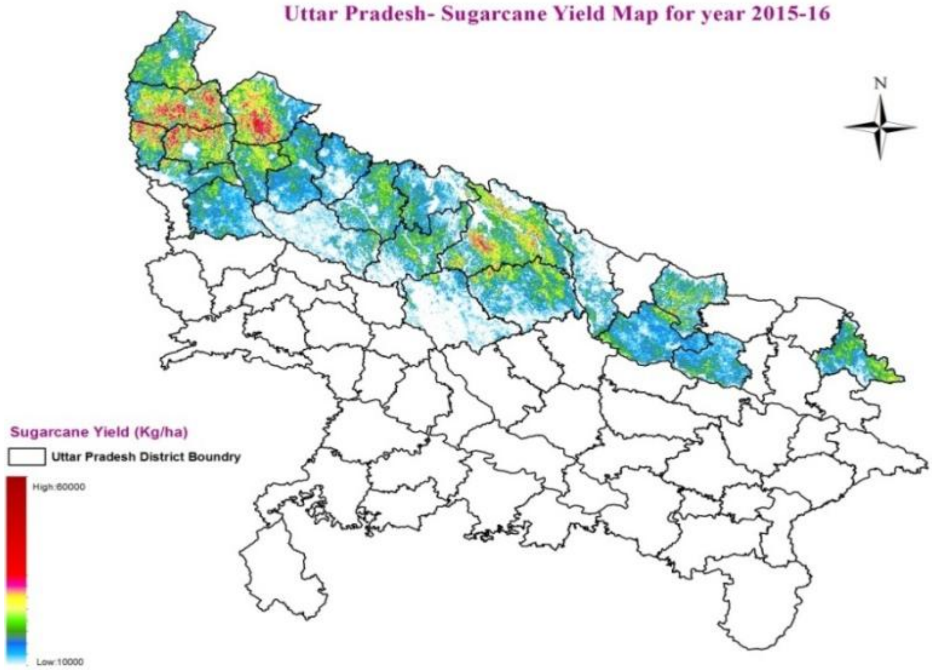

Figure 7. Sugarcane yield map for the year 2015-16

The distributed yield map is shown in Figure 7. It shows the regions of high yield and low yield. However, when compared with DES yield, it was found that the model predicted yield were much lower than the DES yields, with relative deviation ranging between 8.2 to 61.1 per cent. The model generally underestimated the sugarcane yield. The overall RMSE was also high, i.e. 38.4 per cent. The high deviation may be due to the fact that the sowing and harvesting dates for sugarcane crop were highly variable, fields containing ratoon crops and main crop, eksali and adsali etc. Hence, It making difficult to identify the period for which the model should be run. Also, using the same Harvest Index for all the districts may no be correct, because of difference in the variety.

4. Conclusions

This research work is based on Monteith (1977) approach for spectral yield modelling to estimate the Net Primary Productivity of Sugarcane crop in major growing districts of Uttar Pradesh state. The outcome of this study demonstrated that the yield of crop is depending upon the absorbed photo synthetically active radiation and the moisture stress condition of the crop soil system. The product of radiation uses efficiency and harvest index also an important parameter to estimate the net productivity of the crop. The effect of temperature is also observed during the study year to find the net decrease and increase of productivity of crop. After applying temperature stress on final NPP, there was a sudden and abrupt increase of yield values, which was incomparable with estimates of old literature. So the NPP was taken without the temperature effect on the crop.

District wise yield was estimated by applying harvest index on NPP.

The deviation in result of sugarcane spectral yield with DES estimation may be attributed to the error in sowing dates and harvesting dates. This model needs further improvement through the judicious use of temperature stress values, to estimates the yield at district level and also district-wise harvest index values derived from field data.

Acknowledgements

The authors are thankful to the MNCFC FASAL team for providing the Sugarcane crop mask. The first author is grateful to Director, RSAC-UP and Director, MNCFC for providing the opportunity to carry out this work as part of his M. Tech. Dissertation at MNCFC.

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