

SPATIO-TEMPORAL PATTERN OF AGRO ECOSYSTEM NET PRIMARY PRODUCTIVITY OF INDIA: A PRELIMINARY ANALYSIS USING SPOT VGT DATA

R. K. Panigrahy, S. Panigrahy* and J. S. Parihar

Agricultural Resources Group, RESIPA, Space Applications Centre (ISRO), Ahmedabad, India (rkpanigrahy@gmail.com, sushma@sac.isro.gov.in, jsparihar@sac.isro.gov.in)

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ABSTRACT:

Indian landmass with 1.45% of the world's total geographical area accounts for approximately 2.7–5.5% to the global NPP estimates with agriculture contributing to more than sixty percent. This paper reports the spatio-temporal pattern of agricultural NPP in India using SPOT VGT 10-day composite NPP product for 2002-03 to 2004-05 agricultural years. Detailed analysis was carried out for the Indo-Gangetic Region to analyse the temporal pattern of NPP for major cropping systems like rice-wheat, cotton-wheat, rice-rice, rice-potato etc. Results showed that total average crop year (June-May) NPP of Indian landmass was a little higher than 2000 TgC (Terra gram carbon) with more than 60 per cent contribution from agricultural vegetation. Annual rate of fixation for India in a normal monsoon year was high in forest ecosystems (a little more than 1300 gC/m²) than cropland (a little more than 750 gC/m²). Average rate of fixation varied from 900 to 1100 gC/m² for rice-rice, rice-potato and sugarcane-based cropping systems in the Indo-Gangetic Plain (IGP). Significant year-to-year variation (22-25 per cent) in annual NPP was observed depending upon weather condition as it varied from 1881.64 TgC in 2002-03 (a monsoon deficit year) to 2515.22 TgC in 2004-05 (a normal monsoon year). Both agriculture and forest NPP showed a decline of 20-26 per cent in abnormal years.

1. INTRODUCTION

The monitoring of carbon dynamics is a crucial issue in studies of global climate change. Vegetation plays an important role in the carbon cycle. Photosynthesis consumes and respiration produces considerable amounts of CO₂, the predominant greenhouse gas in global warming. Net primary productivity (NPP) has been used as a key indicator of carbon cycle (Lobell et al., 2002). NPP is the rate at which plants accumulate carbon from the atmosphere, and is equal to the difference between carbon gained by photosynthesis, and carbon lost through plant respiration. It is commonly expressed as carbon per unit land area per unit time. NPP has been studied mostly by using point measurements at field level for various ecosystems at local level. However, in recent years, quantification of NPP over large spatial scales is the thrust area of research in the context of global change studies for which mathematical models are used. The NPP modelling has evolved from simple linear regressions between climate variables to sophisticated simulations of interactions among multiple environmental factors by considering either biogeographical or biogeo-chemical processes or both of them (Cramer & Field, 1999; Zhang, 1993; Zhou & Zhang, 1996). The point measurements help the calibration and validation of such models. The gap between both strategies (point measurements and regional modelling) is bridged by the use of remote sensing imagery. The Normalised Difference Vegetation Index (NDVI) derived from near infrared and red band data has been traditionally used for studying vegetation dynamics. Many studies have reported a strong relationship between NDVI and annual above-ground NPP for different geographical areas and ecosystems (Box et al., 1989; Hobbs, 1995; Paruelo et al., 1997). Thus, NDVI as an input for parameterising models that may more accurately reflect actual variations in primary productivity has been the basis of many satellite based NPP models. The NPP products represent

repeatable estimates of the net flux of carbon between the atmosphere and terrestrial vegetation. It quantifies these carbon fluxes by combining a simplified carbon exchange model with satellite observations. During the past one decade, space borne Remote Sensing data has been increasingly used to model spatial pattern of regional and global NPP (Gao et al., 2000, Ni et al., 2000).

However, most of the studies on NPP have been concentrated on natural vegetation with very little attempt for agricultural vegetation. Given the obvious differences in NPP responses between natural and agricultural vegetation, it is essential to study agricultural NPP, particularly for countries like India, where, it is the major land use. Zheng *et al.* (2005) obtained significant differences in results when NPP model specifically for agricultural vegetation was used instead of the natural vegetation model in China. Indian landmass with 1.45 per cent of the world's total geographical area accounts for approximately 2.7–5.5 per cent of the global NPP. Agriculture is the dominant land use class in India, which is under constant change driven by socio-economic, technology and many other factors. Though some studies had been carried out on total and agricultural NPP of India (Chabra and Dadhwal, 2004, Hooda et al., 1996), the contribution of different agroecosystems has not yet been explored. This paper reports the spatio-temporal pattern of NPP in agro ecosystems of India in general and in different cropping systems in the Indo-Gangetic Plain (IGP) in particular using the SPOT VGT NPP data.

2. DATA USED AND METHODOLOGY

2.1 Satellite imagery

SPOT-VEGETATION NPP products used in this study are generated from the SPOT VGT S10 NDVI (Normalised

*Corresponding author

Difference Vegetation Index) products that are the Maximum value composite (MVC) of daily synthesis from ten consecutive days. The MVC is commonly employed to mitigate unwanted atmospheric and view angle effects, in daily NDVI images by 'collapsing' them into mosaics composed of the highest NDVI for each location over a pre-specified time period by sequentially comparing pixels (Holben, 1986). The NPP computing model known as "C fix" is based on the Monteith-approach and requires three fundamental inputs: a remote sensing variable (NDVI) and two meteorological variables (daily incoming solar radiation and mean air temperature). The estimates of NPP are provided in $\text{mgC/m}^2/\text{day}$.

Since, the agricultural activity in India is governed by crop seasons, analysis was carried out for the agricultural years (i.e. 1st June to 31st May). Analysis was carried out for two crop years representing a normal monsoon year (2004-05) and a drought year (2002-03). The generated standard NPP products for W-Asia in compressed format were downloaded from the URL: <http://gmes.vgt.vito.be/geosuccess/relay.do>. There were total 72 scenes (36-products covering each year) stacked to a single database. The image for India was clipped from the database of West Asia. The multi-date image dataset was reprojected using Albers Conic Equal Area projection with WGS84 Earth Model based on a nearest neighbourhood sampling. Analysis was carried out using the image-processing package PCI Geomatica V9.1.0.

2.2 Ancillary data

Ancillary data used were the land use/cover map, cropping pattern and crop rotation map for same years, state and country administrative boundary. The country and state boundaries based on the Survey of India maps were overlaid on the image database to extract the area of interest for further study. The landuse/landcover layer from International Geosphere Biosphere Programme (IGBP) was used to create masks of the land use/cover classes (USGS, 2005). The original 17 classes were merged to obtain broad classes of permanent vegetation including forest, agricultural land, water and others (urban, sand etc.) and used to analyse the seasonal and annual NPP in general and for agricultural area in particular. Detailed analysis on NPP in relation to cropping systems was carried out for the IGP covering the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. An existing cropping pattern map and crop rotation map of the area was used for this purpose. The annual and

seasonal patterns of daily NPP and cumulative NPP were analysed. The cumulative NPP values were generated by multiplying the daily mean values with a multiple factor equal to the number of averaging days. Further analysis of NPP pattern was carried out for some important crops and crop rotations for the IGP. The cropping systems studied are rice-wheat, cotton-wheat, rice-rice, rice-potato, maize-wheat and sugarcane based.

3. RESULTS AND DISCUSSION

India has a geographical area of 328.73 Mha with reporting area for land utilisation statistics 304.92 Mha. Agriculture is the major land use followed by forest. The net sown area and forest constitute around 46.6 and 22.5 per cent, respectively of the reporting area. Around 35 per cent of the agricultural area is cultivated more than once, thus taking the cropping intensity to around 135 (DES, 2004). Thus, it is very clear that, agriculture plays the dominant role in Indian NPP scenario. Analysis of VGT NPP data showed that under normal monsoon performance (June 2004-May2005) the NPP of Indian landmass is 2519.13 Tg. This amounts to the area weighted terrestrial NPP of $8.26 \text{ tCha}^{-1}\text{yr}^{-1}$. Forest accounted for around 30 per cent of the total NPP. Agriculture accounting for a little more than 60 per cent of total NPP is the largest contributor to the terrestrial NPP. Reduction of around 28 per cent in total NPP is observed in a monsoon deficit year (2002-03) making the area weighted NPP as $5.95 \text{ tCha}^{-1}\text{yr}^{-1}$. Reduction of NPP in the monsoon deficit year in the agriculture and forest was of the order of 26 and 21 per cent respectively showing strong influence of precipitation on terrestrial NPP. Earlier studies (Cao et al., 2004) have reported a strong positive correlation between NPP and precipitation. The temporal pattern showed that, the peak fixation for the forest class occurs during the month of October. In case of agriculture, there were two peaks, a major one during September-October and another during February-March. This matched with the cropping pattern followed in India. Further analysis of NPP pattern of important crops and cropping systems was carried out for the IGP comprising of five states. Analysis showed that this region contributes around 18 per cent to total terrestrial NPP and a little more than 30 per cent of to total agricultural NPP. The region being predominantly agriculture, the agricultural NPP constitutes around 87 per cent of total NPP. Figure 1 shows the temporal pattern NPP from agricultural area in India and the IGP in relation to forest ecosystem of India during a normal monsoon year (2004-05).

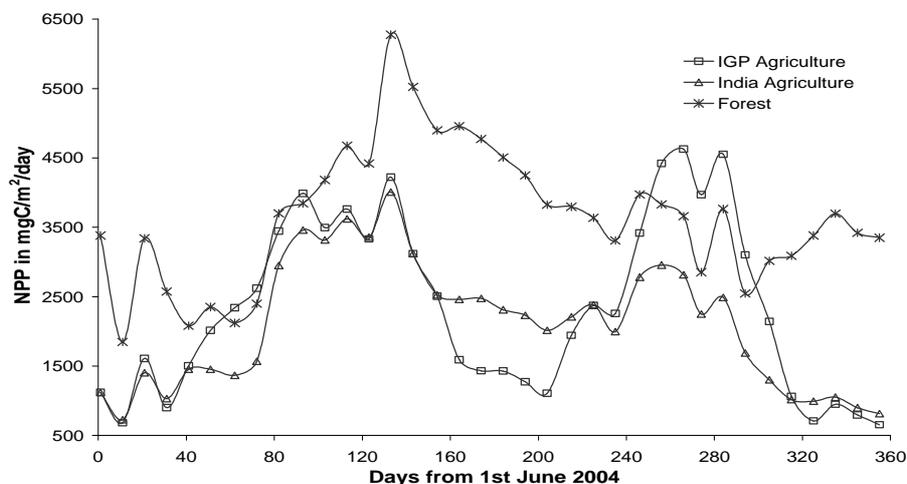


Fig. 1 Temporal pattern of NPP of agriculture area in India and IGP in relation to forest ecosystems during 2004-05 (a normal monsoon year)

The area weighted NPP calculated for IGP agricultural land was 851.25 $\text{gCm}^{-2}\text{yr}^{-1}$ 2004-05 compared to India agricultural NPP of 766.73 $\text{gCm}^{-2}\text{yr}^{-1}$ for the same year. During 2002-03, the IGP agricultural NPP was 696.33 $\text{gCm}^{-2}\text{yr}^{-1}$ amounting to 20 per cent reduction in the monsoon deficit year (Table-1).

Crop year (June to May)	NPP (TgC)		
	India Total	IGP Total	IGP Agricultural
2002-03	1814.45	356.09	314.48
2004-05	2519.13	448.35	392.64
Difference (%)	27.97	20.58	19.90

Table-1 Total NPP (TgC) of IGP and terrestrial India- a comparative statistics generated using SPOT NPP for 2002-03 and 2004-05 crop year.

Further analysis was carried out for the crop rotation classes in IGP. The rotation map used in this study showed that two crop rotations were the dominant ones in IGP. Rice-wheat rotation emerged as the major rotation occupying around 41 percent of the agricultural area. The other major crop rotations studied were maize-wheat, pearl millet-wheat, rice-rice, cotton-wheat, rice-potato and sugarcane based. The temporal pattern Analysis showed that August-September coincide with the peak NPP of

wet season cropping pattern while February-March showed the peak of dry season cropping pattern (Fig. 1) Among the different crop rotations, sugarcane based and rice-potato rotations have high NPP with 1089.69 $\text{gCm}^{-2}\text{y}^{-1}$ and 1142.33 $\text{gCm}^{-2}\text{y}^{-1}$ respectively during 2004-05.

Comparison of 2002-03 and 2004-05 NPP showed that, deficit monsoon year caused significant reduction in NPP of all the cropping systems. Rice-potato, rice-rice and cotton-wheat rotations were found to be more sensitive showing around 30 per cent reduction (Fig. 2). Temporal analysis showed that the reduction in total NPP was mainly due to reduction in wet season NPP (Fig. 3).

The spatial pattern of NPP during 2004-05 in IGP shows high NPP in most of Punjab, Haryana and southern West Bengal (Fig. 4). Maximum NPP for sugarcane-based system was observed to be 1600 $\text{gCm}^{-2}\text{y}^{-1}$ for a site in Saharanpur district, UP. Maximum NPP for rice-potato and rice-rice was observed to be 1446.0 $\text{gCm}^{-2}\text{y}^{-1}$ and 1698.0 $\text{gCm}^{-2}\text{y}^{-1}$ respectively at locations in West Bengal (Table-3). Since, no actual NPP measurements are available for agricultural systems in India, the results were compared with that of natural grasslands. The NPP estimated from actual measurements at field level for the natural grasslands in the IGP region in India varied from 1082 and 1391 $\text{gCm}^{-2}\text{yr}^{-1}$ (Pandey and Singh, 1992). This gives an indication that NPP of the major cropping systems of IGP is very close to that of the natural savanna grassland systems.

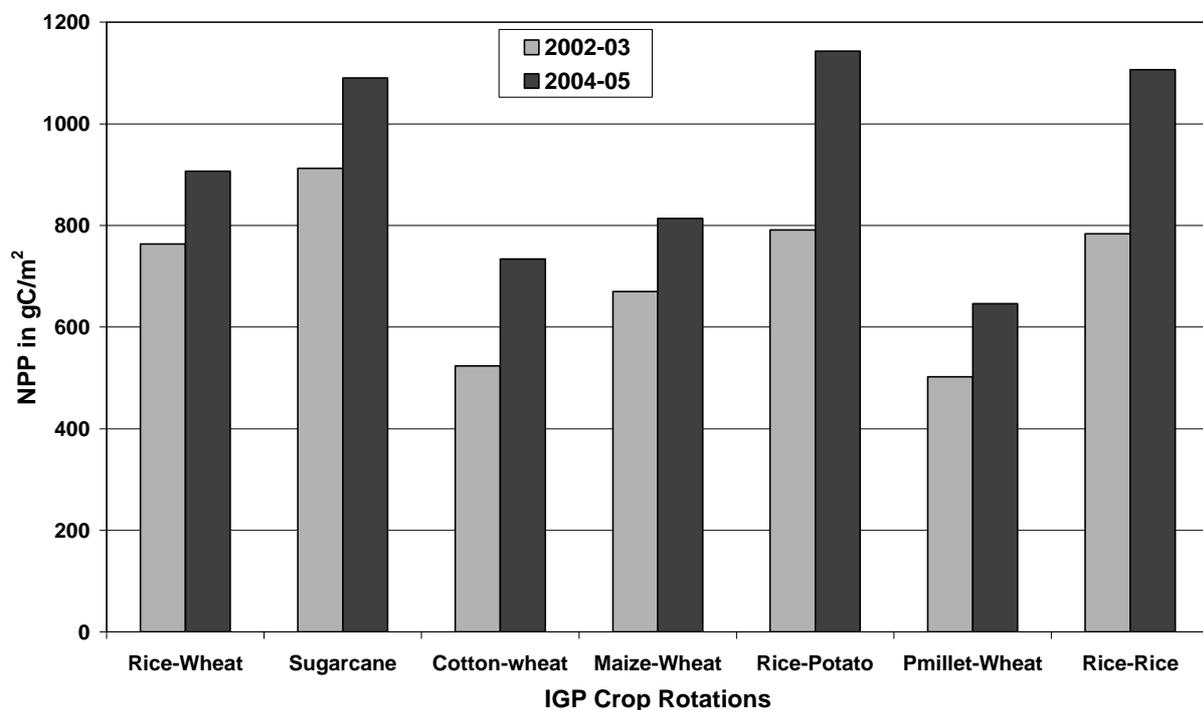


Fig. 2 Variation in mean NPP for major crop rotations in IGP in a normal monsoon year (2004-05) and a monsoon deficit year (2002-03)

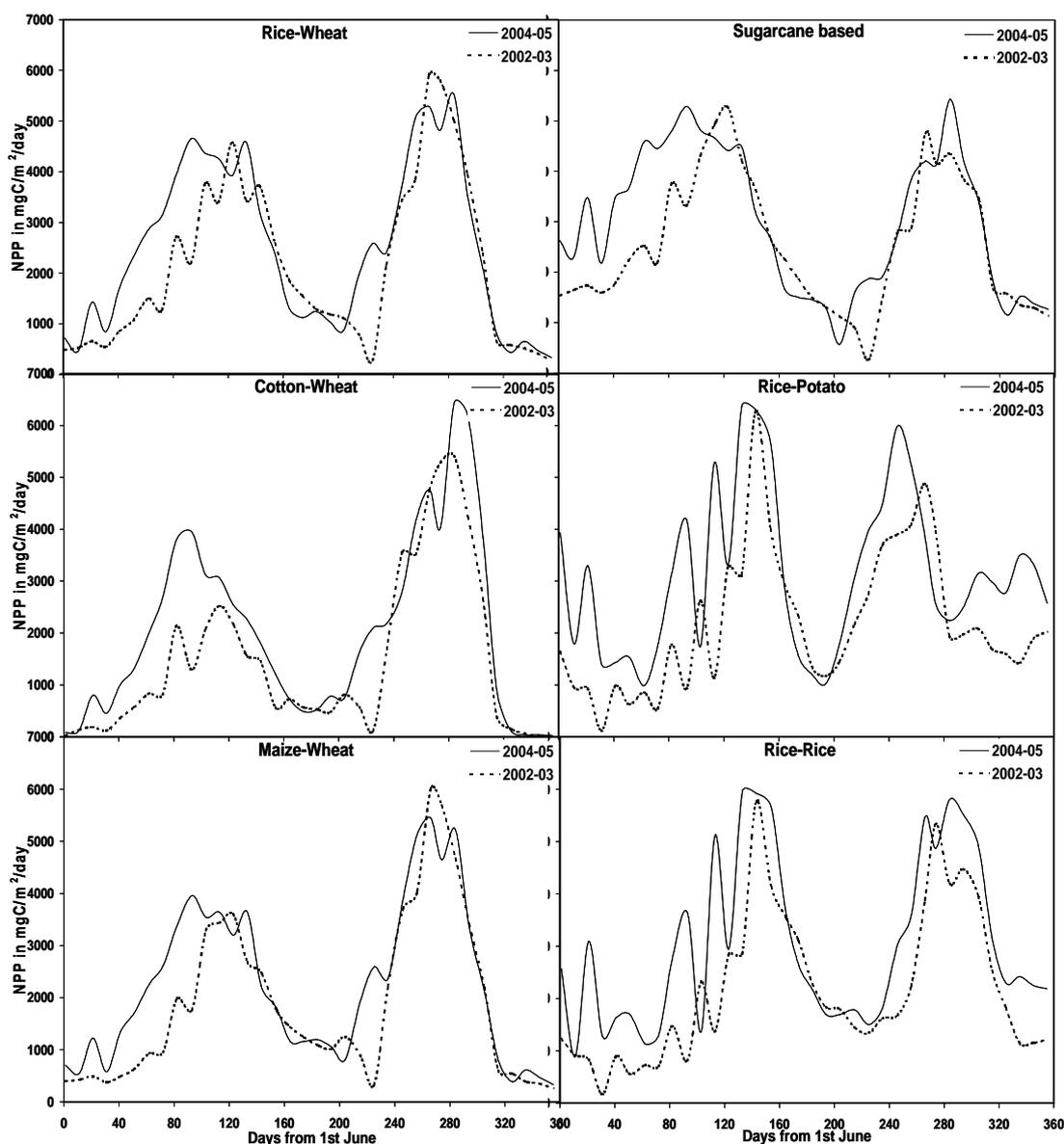


Fig. 3. Temporal pattern of NPP for major crop rotations in IGP during a normal and deficit monsoon year (2004-05 and 2002-03 respectively)

Serial No.	Crop Rotation	NPP (2002-03)		NPP (2004-05)		Location of Max NPP
		Mean	Max	Mean	Max	
1	Sugarcane based	904.05	1514.0	1089.69	1600.0	Saharanpur (UP)
2	Rice-Potato	785.01	1006.0	1142.33	1446.0	Hoogly (W.B.)
3	Rice-Rice	769.24	1000.0	1106.32	1698.0	East Midnapur District (W.B.)
4	Rice-wheat	753.50	1404.0	906.39	1442.0	Pilibhit (UP)
5	Cotton-Wheat	519.05	759.0	733.10	1033.0	Muktasar (Punjab)
6	Maize-Wheat	658.70	1272.0	13.07	1340.0	Roopnagar (Punjab)

Table-3 Mean and maximum NPP (gC/m^2) observed for major crop rotations in IGP observed during 2002-03 and 2004-05 along with the location of maximum NPP.

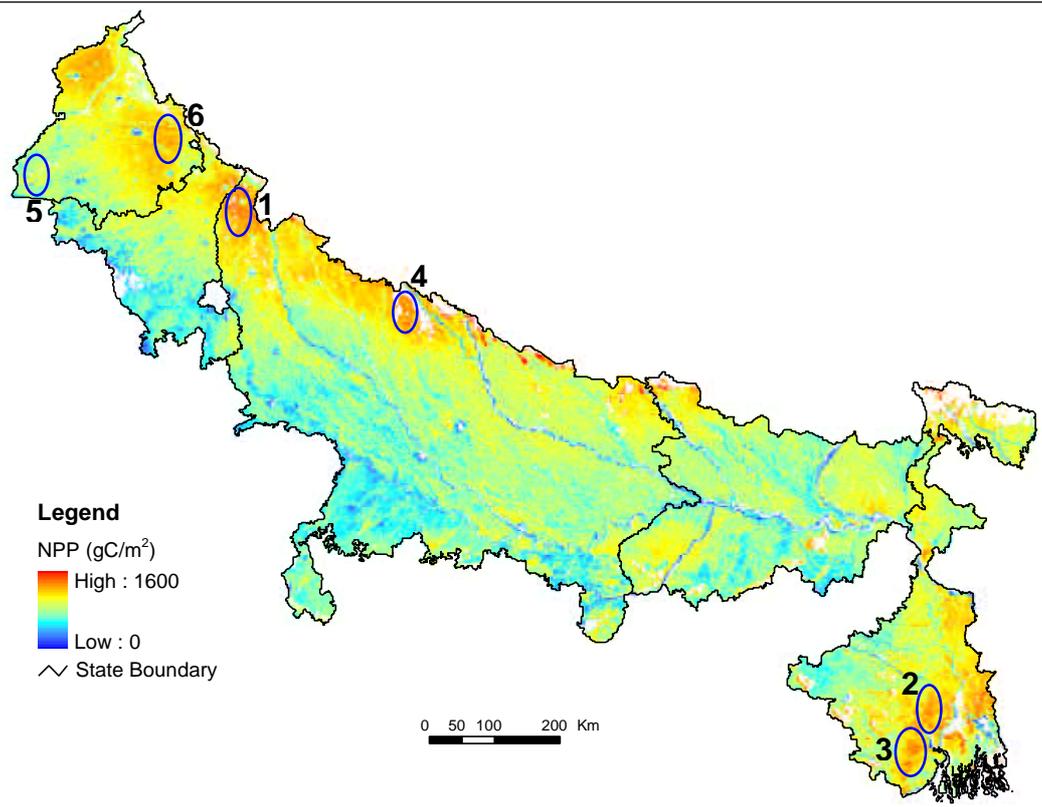


Fig. 4 Spatial Pattern of NPP in IGP during 2004-05 showing locations of highest NPP observed for different crop rotation classes (for locations refer Table-3 against numbers on the figure)

4. CONCLUSION

Understanding and estimating NPP of agricultural system is essential to understand the biogeochemical cycle. The present study is first such attempt to study the spatio-temporal pattern of NPP in relation to different crops and crop rotations over a large area using satellite remote sensing data. The results obtained may have some error in absolute quantification since the SPOT VGT NPP product is yet to be validated over Indian region. However, the temporal and inter-annual pattern obtained are informative and matches with other collateral data on crop area, productivity and management practice. The study could highlight strong seasonal variations among the rotations and year-to-year variation due to monsoon performance. Further study to calibrate the “C fix” model for India agro ecosystems and validate the NPP products from SPOT VGT and MODIS are planned. Since, ground measurements are essential in order to construct any models and independently validate them (Long et al, 1992), this study provides baseline information to design such study.

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