SPATIAL DATABASE GENERATION OF THE RICE-CROPPING PATTERN OF INDIA USING SATELLITE REMOTE SENSING DATA

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ABSTRACT:

Rice is one of the key food grains linked to the food security of the growing population of the world. India has largest rice area in the world and stands second in production. The rice crop is important both from the food security and climate change point of view. The present paper highlights rice-growing pattern in India derived using satellite remote sensing and Geographic Information System. Multidate SPOT VGT 10-day composite normalised difference vegetation index data is used along with RADARSAT SAR and IRS WiFS data to map the rice area and generate seasonal rice cropping pattern and crop calendar. The spectral growth profiles of rice crop clusters were modeled to derive spatial patterns crop rice calendar. The results showed that there are two major rice cropping pattern; wet season and dry season. The wet season rice calendar varied significantly. The transplantation starts as early as mid April in Jammu. The transplantation in main land India starts from Punjab by end of May and progresses towards eastern states. Out of 43 Mha of total rice lands, wet season occupied 88.8 per cent. Comparatively, less variation of rice transplantation observed during dry season. The average crop duration of wet rice crop was more than dry season rice by 17 days. The prominent states growing dry season crop are West Bengal, Andhra Pradesh and Orissa. Rotation wise, rice- rice rotation accounted for 7.97 percent of the total rice area, mainly found in West Bengal, Andhra Pradesh, Tamilnadu and Orissa. West Bengal state has nearly 31.7 percent area under rice-rice rotations. This is the first time that a spatial data base of rice cropping pattern and crop calendar of India is generated, which will serve as baseline data for relevant simulation studies on climate change and green house gas emission.

1. INTRODUCTION

Rice is one of the key food grains linked to the food security of the growing population of the world. India has largest rice area in the world and stands second in production. The system is also more vulnerable in the context of climate change. In addition Rice cultivation has been accredited as one of the most important source of anthropogenic methane with estimates of annual emission ranging between 47 and 60 Tg/yr, representing 8.5-10.9 percent of total emission from all sources. (Crutzen, 1995 and Houghton et al, 1995). Rice is a dominant agricultural system in India and Asia and holds the key to sustaining the food security of the most populated belt of the world. The importance of rice crop and its vulnerability in the context of climate change becomes relevant only with reliable national level spatial database for monitoring, mitigation and modeling purposes. The issue with Indian rice systems is the diversity in geographical distribution pattern and crop calendar. A significant feature of the last two decades is the application of new technologies for effective land management. The lacuna in acceptable spatial information can be filled with the availability of multi temporal satellite based remote sensing techniques. Remote sensing data offers a wide spectrum of ground resolution that is ideally suited for various scales of mapping. GIS is a computer-assisted system for the capture, storage, retrieval, analysis and display of spatial and non-spatial data. Multi-temporal satellite data is the only feasible source of monitoring large agricultural units to create a spatial database of the variant components of the existing agro-ecosystem. Studies carried out within the country and elsewhere have demonstrated that multispectral remotely sensed data could be used effectively to identify major crops and to determine their area of extent (Manjunath et al, 2000, Dadhwal et al, 2002).

Various aspects of rice crop mapping, monitoring and modelling using remote sensing data is widely reported from many countries (Geiser and Sommer, 1984, Panigrahy et al., 1992, Kurosu, 1995, Ribbes 1999, Chakraborty et al. 1993). Similarly, multidate, multiyear data can be used to derive the seasonal pattern of rice (autumn, winter, summer crops), crop rotation etc. (Panigrahy et al., 2003). In addition, all these information are derived in spatial scale and are amenable to mapping at different scales. The derived outputs like these forms the significant input to climate change studies. The launch of Indian Remote Sensing (IRS) series of satellites has ensured a steady supply of RS data of various spatial, spectral and temporal resolutions to the users. Of late, SPOT vegetation (VGT) has been found very useful to study the dynamics of agricultural system at regional level. The spot vegetation (VGT) has a similar temporal resolution and nadir spatial resolution as AVHRR, but it shows significantly better performance with regard to geometric fidelity, radiometric calibration, multi-temporal registration, and absolute geolocation (Saint, 1996; Stroppiana et al., 2002; Zhang et al, 2003). With the availability of microwave SAR data from ERS and Radarsat SAR, another dimension to crop information is added (Panigrahy et al., 1999).

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Microwave sensors can penetrate cloud, fog, rain and darkness enabling data acquisition whenever required, thus, is perceived as a suitable alternative for rice crop monitoring. The use of radar for rice monitoring has gained momentum in recent years with the launch of C-band (5.4 GHz) satellites like ERS-1, 2, and RADARSAT-1, which provide Synthetic Aperture Radar (SAR) data. Many studies were conducted which highlighted the unique temporal backscatter of wetland rice fields in many parts of Asia (ESA, 1995, Kurosu, 1995, Ribbes 1999, Liew, 1998, Panigrahy et al.,1999, 2000, and Le Toan, 1997). The management practice of growing wetland rice in flooded fields gives a unique temporal signature in C band data. Multidate data acquired during the growth period of a crop can be effectively used to derive the crop calendar, progress of sowing and harvesting. Chakraborty et al. (2000) used calibrated temporal SAR data to characterize the normal growth profiles of rice grown in a rainfed region in India. The SPOT VGT and NOAA AVHRR sensors offer high temporal data which aids in capturing the spatio-temporal dynamics of vegetation through modeling. Rice is the major wet season crop in India and there are many double and triple cropped areas also which account for around 44.5 Mha (DRR, 2002). The average Indian rice area of year 2002 to 2006 was 42.91 Mha (standard deviation of 1.69 Mha) with 39.09 (91.1%) and 3.82 (8.9%) Mha during kharif and rabi seasons, respectively. The present paper highlights technique and results of remote sensing based seasonal rice-growing pattern and diversity in rice calendar in India.

2. MATERIAL AND METHODS

2.1 Study area and data used

The rice crop is grown in all most all parts of the country. The study area encompassed the entire rice growing regions of the country. Multi source multi-temporal satellite data was used in the study. The methodology involved the use of RS data for deriving rice crop area and characterizing rice crop phenology. The collateral data has been used for assigning RS derived pixels to respective rice categories. Seasonal rice maps, rice transplantation maps and rice crop dynamics were derived using following satellite data:

1. Multidate SPOT 4 VEGETATION S10 NDVI composites (April 2001-May 2002)
2. Multidate Radarsat ScanSAR Narrow Beam (SN2) (C-band, HH-polarisation, 50m resolution, 300 km swath) for kharif 2005-06.
3. Indian Remote Sensing (IRS) Wide Field Sensor (WiFS) data of rabi 2005-06

SPOT VGT: The Vegetation optical instrument, a wide field of view sensor on board of the SPOT-4 earth observation satellite launched in March 1998, operates in 4 spectral bands: Blue (0.43-0.47), mainly to perform atmospheric corrections. Red (0.61-0.68) and Near Infrared (NIR) (0.78-0.89) are sensitive to the vegetation's photosynthetic activity and cell structure respectively whereas Short Wave Infrared (SWIR) (1.58-1.75) is sensitive to soil and vegetation moisture content. Its 1 km spatial resolution is nearly constant across the whole 2,250 km corridor it covers, which means that there is almost no distortion on image edges. Two main products are offered, both geometrically and radiometrically corrected and projected in a standard or user-defined cartographic projection. Primary products that represents extract of a segment along a single orbit, mainly for scientific use. Since they are not atmospherically corrected their values correspond to reflectance at the Top of the Atmosphere -TOA - (at the moment of acquisition). The data were downloaded from the SPOT free website www.free.vgt.vito.be. Data consist of daily synthesis from ten consecutive days. Each 10-day composite data consists of scaled Normalized Difference Vegetation Index (NDVI). The methodology used for rice crop discrimination has been described by Manjunath et al, 2006.

Synthetic Aperture Radar data was used for the Kharif season (July to October) as it has the imaging capability under cloud cover. Canadian satellite Radarsat SAR provides data at C band (5.3 GHz) HH polarization. Radarsat ScanSAR Narrow beam data (SN2) with 50 m resolution, swath of 300 km and 31^0-46^0 incidence angle is now operationally used to monitor kharif rice in India under another national project (FASAL: Forecasting Agricultural output using Space, Agrometeorolgy and Land based observations). Thus, the same data was used to map the rice area of the sampling states (WB, UP, Punjab, Haryana, Bihar, Jharkahnd, Assam, Madhya Pradesh, Chattisgarh, Karnataka, Tamilnadu, Andhra Pradesh and Jammu and Kashmir) during 2005-6 season for spatial flux pattern generation. Three date data with 24 day repeat cycle was used. The methodology described by Chakraborty and Panigrahy, 2000 was used for discrimination of rice pixels using SAR data. Fig. 1a shows a typical three date color composite of SAR data example (covering West Bengal state).

The IRS 1C/1D WiFS data was used for deriving the rabi (2005-6) rice crop maps of West Bengal, Orissa, Assam, Bihar, Andhra Pradesh, Karnataka and Tamilnadu. The sensor provides 188 m spatial resolution data in Red and NIR bands with 750 Km swath. The large swath data is conducive for state level mapping. A supervised classification with maximum likelihood classification scheme was used for deriving rice maps. Fig. 1b shows the typical WiFS FCC (showing WB state coverage). Finally a wet season and dry season rice maps of India was generated.

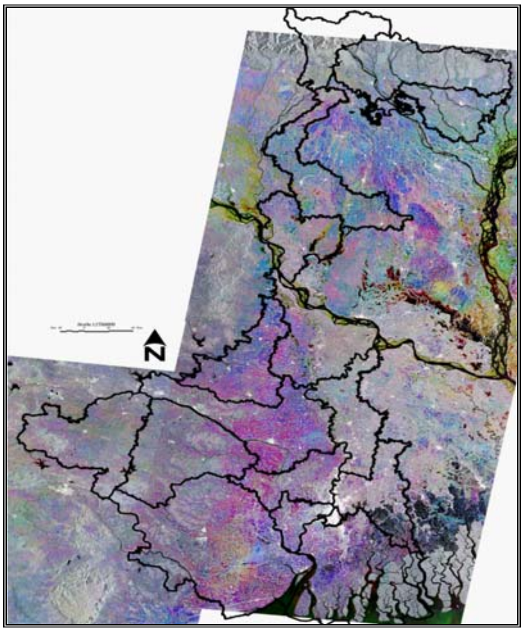

Figure 1a. The three date Radarsat ScanSAR FCC

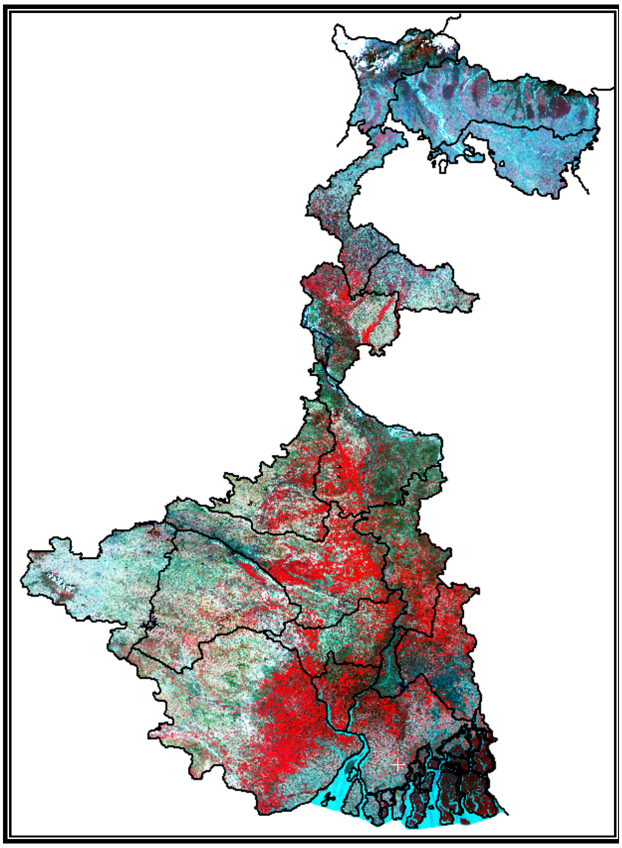

Figure 1b. The IRS-1C WiFS FCC

2.2 Generation of Seasonal Rice Maps

2.2.1 All India seasonal rice map: There are two major rice growing seasons in India. The main one is the wet season called kharif and the second one is dry season or rabi. Kharif season extends from May to November and Rabi season from January to April. To account for all the rice lands and carry out stratification, it is thus essential to create seasonal rice maps of the country. The seasonal rice map of India was generated using multidate SPOT S 10 NDVI product. Temporal S10 data were georeferenced using the Lambert conformal conic (LCC) projection and Everest (earth model) referencing scheme and co-registered. The country and state boundaries were overlaid. Further analysis was carried out within the mainland area of India. The cloud cover contaminated data were excluded as per the methodology suggested by Narendra and Fukunaga, (1977), which resulted in an average of 25-28 dates for different states. Classification of S-10 data was carried out using a two-step approach (Manjunath et al, 2006). A decision rule classifier was used to exclude forest, settlements and water bodies.

The rest of the area outside this mask was treated as potential agricultural area. Further classification was carried out within this mask. Data from May to November were used to derive the wet season rice known as kharif that is grown in almost all the states. Data from November to May were used to derive dry season rice, confined to a few states. The Iterative Self-Organizing Data Analysis Technique (ISODATA) (Tao and Gonzalez, 1974) was used to classify temporal S -10 data. In general 20 classes and 15 iterations were used. The rice classes were assigned based on ground truth data. Correctly classified classes were masked and a second unsupervised classification (ISODATA) was performed for the remaining area until no further increase in class separability was achieved. Six to eight locations for each state were used to check for the correctness of the classification using ground data. A similar approach has been used for land cover mapping using VGT data (Ledwith, 2004). The seasonal rice maps thus derived were superimposed to derive an integrated rice map (shown as kharif, rabi and both).

2.2.1.1 Kharif rice area map of 2005-6: ScanSAR data were used to generate the kharif rice map for the study states viz. J&K, Punjab, Haryana, UP, Bihar, WB, Assam, Orissa, MP, Chattishgarh, AP, Karnataka and Tamilnadu. Three date data acquired with 24 day gaps were used for this. The mapping was based on hierarchical classification based on decision rules as followed in the National Rice Production Forecasting of FASAL project (Chakraborty and Panigrahy, 2000).

2.2.1.2 Rabi rice map of 2005-6: This was generated using single date IRS WiFS data for the major rabi rice growing states of Orissa, WB, AP and Karnataka. A two-step classification of unsupervised to delineate non-agriculture classes followed by supervised classification to delineate rabi rice area was followed. Ground truth data for classification was used from other available project work and reports/maps.

2.3 Rice Crop Calendar/Phenology

It is essential to have the crop calendar in terms of planting and maturing, important growth stages etc for a variety of applications. India has a high diversity in rice crop calendar. Though some data is available in this regard, hardly there exists any spatial (map format) database. In the present study, this information was derived using the remote sensing data. Since, high temporal data is essential for such study, the SOPT VGT data was used for this purpose. The canopy reflectance in the red spectral region decreases due to increased chlorophyll absorption; whereas it increases in the near IR (NIR) owing to an increase in spongy mesophyll structures with advancement in crop growth stage. The vegetation index, NDVI derived by normalized differencing of the visible and NIR radiance is a strong indicator of the total green biomass at any given time. Thus, the temporal data from beginning to end of growing season can be modeled to derive various plant growth parameters like crop emergence, peak growth etc (Badhwar 1985 and Crist and Malila, 1980). In the present study the crop growth equation given by Badhwar (1985) is used to derive the growth parameters as below:

$$(t \geq t_0) = G_0(t_0)(t/t_0)^{\alpha}\mathrm{Exp}[-ß(t^2-t_0^2)] \text{ and } G(t < t_0) = G_0$$

where G(t) is a quantity measuring green biomass at time t, t_0 is spectral emergence date, G_0, α and ß are growth parameters. Following Boatwright et al. (1988), the NDVI representation is used to fit the above growth equation. The Badhwar (1985) growth profile model equation is non-linear in the parameters and needs to be non-linear least square fit. The parameters G_0, α and ß can be retrieved by inverse transformation of equation. The time of attainment of maximum vegetative cover, t_{max} is related to α and β by $t_{max}=(\alpha/2ß)^{1/2}$. The SPSS v15.0, mathematical software was used for fitting the equation and deriving the parameters for major clusters of rice crop within each state. The spectral profiles of the selected rice classes were plotted for each state. The Julian days on which the spectral emergence peaks and maturity occurs were marked from the characteristic pattern of spectral values. Based on this the planting period, duration of growth and maturity periods was determined.

3. RESULTS AND DISCUSSION

3.1 Seasonal Rice Maps

The state-wise wet and dry season rice area derived using remote sensing data is presented in table 1 and Fig. 2. The total rice area obtained was 43.099 Mha. The wet season rice area was 38.529 Mha while the dry season rice area was 4.82 Mha. Though, conventionally, wet season ends by November, the main rice crop of Tamilnadu (known as Samba crop) that has shifted crop calendar (October –January) is shown as Kharif crop (Fig 2). The comparison of remote sensing (RS) and reported estimates of rice area for corresponding year showed that RS estimates were higher by 0.92%. However higher deviations were observed at state level.

	Wet Season		Dry Season		Total	
STATE	**Area**	**Percentage to wet season**	**Area**	**Percentage to Dry season**	**Area**	**Percentage to Total**
AP	3,447.3	8.95	1,174.7	25.70	4,622.0	10.72
ASSAM	2,024.4	5.25	116.6	2.55	2,141.1	4.97
BIHAR	4,159.5	10.80	405.8	8.88	4,565.3	10.59
GUJ	691.6	1.79			691.5	1.60
HAR	763.4	1.98			763.4	1.77
HP	284.7	0.74			284.7	0.66
J&K	376.6	0.98			376.6	0.87
KAR	1,172.5	3.04	484.0	10.59	1,656.5	3.84
KER	337.6	0.88	391.6	8.57	729.2	1.69
MH	1,919.8	4.98			1,919.7	4.45
MP	5,337.7	13.85			5,337.7	12.38
ORISSA	3,603.2	9.35	122.5	2.68	3,725.6	8.64
PUNJAB	2,112.0	5.48			2,111.0	4.90
RAJ	183.0	0.48			183.0	0.42
TN	1,511.3	3.90	255.3	5.30	1,766.6	4.10
UP	5,536.2	14.37			5,536.2	12.85
WB	4,490.4	11.65	1,875.2	41.03	6,365.6	14.77
NE STATES	322.4	0.84			322.4	0.75
TOTAL	38,529.0	88.80 (Wet)	4,825.7	11.20 (Dry)	43,099.3	

Table 1: Rice Area Derived Using Remote Sensing data (Thousandha)

3.2 Rice Crop Phenology

The spectral growth profile of rice crop modeled (Badhwar et al, 1985) using temporal SPOT VGT data is presented in fig. 3. The profile parameters are presented in table 2. A wide diversity with respect to paddy transplantation was observed during the wet season. The transplantation starts as early as mid April in Jammu and Kashmir with rise in temperature and availability of water through melting of ice. The transplantation in main land India starts from Punjab by end of May and progresses towards eastern states. The planting ends in Tamilnadu where the crop is transplanted during middle of September. The major reason for such high diversity during the wet season is the diversity in rainfall onset and distribution. Small variation of rice transplantation observed during dry season is attributed to the availability of irrigable water and land availability (after the kharif crop).

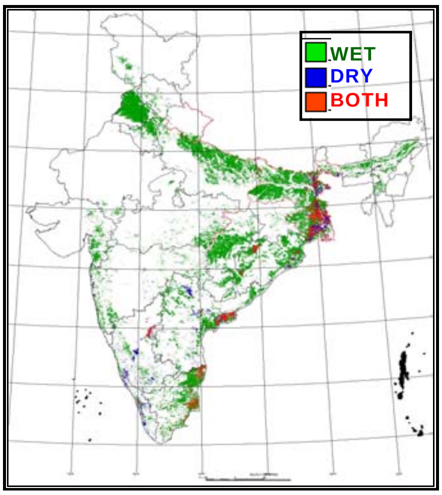

Figure 2. The Rice Map of India Derived Using Satellite Data

DRY SEASON					
State	Tmax (JD)	G0	T0 (JD)	ALPHA	BETA
AP	411	0.374	338	19.07	5.6E-05
KAR	426	0.300	350	25.77	7.1E-05
BIHAR	405	0.363	350	30.00	9.1E-05
WB	429	0.313	363	30.00	8.2E-05
ORISSA	435	0.282	373	30.00	7.9E-05
ASSAM	437	0.325	374	38.16	1.0E-04
WET SEASON					
AP	276	0.100	182	15.82	1.0E-04
ASSAM	255	0.187	172	10.86	8.4E-05
BIHAR	272	0.103	181	16.99	1.2E-04
HARYANA	235	0.203	156	9.90	9.0E-05
JK	203	0.258	119	5.13	6.2E-05
KAR	286	0.189	187	8.69	5.3E-05
MP	267	0.143	177	13.16	9.2E-05
ORISSA	263	0.069	152	11.46	8.3E-05
PUNJAB	225	0.250	150	8.76	8.6E-05
UP	248	0.235	155	6.63	5.4E-05
TN	354	0.289	291	30.00	1.2E-04
WB	278	0.160	192	15.12	9.8E-05

Table 2: The profile Parameters of Major Rice Clusters

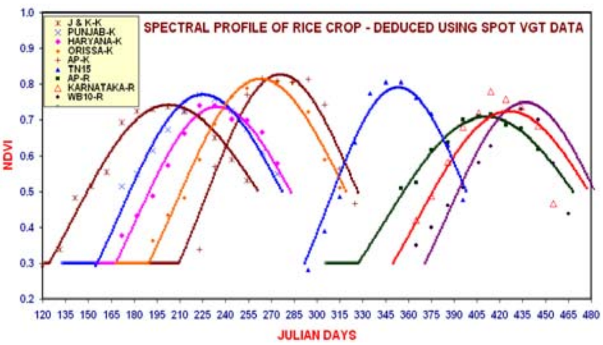

Figure 3. The rice crop - growth profile curve derived using multi-temporal SPOT VGT data (K-Kharif, R-Rabi)

The table 3a and 3b shows the date of transplantation (DAT), date of maximum crop cover (T_{max}) and crop maturation (Maturity) derived from the rice-spectral-profile.

Wet Season	DAT	T_{max}	Maturity
AP	30-Jun	2-Oct	21-Nov
ASSAM	20-Jun	10-Sep	30-Oct
BIHAR	29-Jun	27-Sep	16-Nov
HARYANA	3-Jun	21-Aug	10-Oct
JK	27-Apr	20-Jul	8-Sep
KAR	4-Jul	6-Oct	25-Nov
MP	25-Jun	23-Sep	12-Nov
ORISSA	10-Jul	19-Sep	8-Nov
PUNJAB	29-May	12-Aug	1-Oct
UP	2-Jun	4-Sep	24-Oct
TN	16-Oct	18-Dec	6-Feb
WB	10-Jul	3-Oct	22-Nov
Average (India)	27-Jun	18-Sep	7-Nov

Table 3a: The Wet Season Rice Crop Calendar of India Derived Using Satellite Data

Dry Season	DAT	T_{max}	Maturity
AP	3-Dec	14-Feb	5-Apr
KAR	15-Dec	1-Mar	20-Apr
BIHAR	15-Dec	8-Feb	30-Mar
WB	27-Dec	3-Mar	22-Apr
ORISSA	7-Jan	10-Mar	29-Apr
ASSAM	7-Jan	11-Mar	30-Apr
Average (India)	23-Dec	26-Feb	17-Apr

Table 3b: The Dry Season Rice Calendar of India Derived Using Satellite Data

The transplantation date information was used for rice clusters and a rice transplantation image was generated (Fig. 4). It is clear from the table 3 that the average crop duration is 116 days during dry season and about 133 days during wet season. The day of spectral vegetation period during the dry season was 66 after transplantation while it is 83 days during wet season. The third week of June is the average day of sowing during wet season and peak growth is achieved by 18th September and generally crop matures by first week of November.

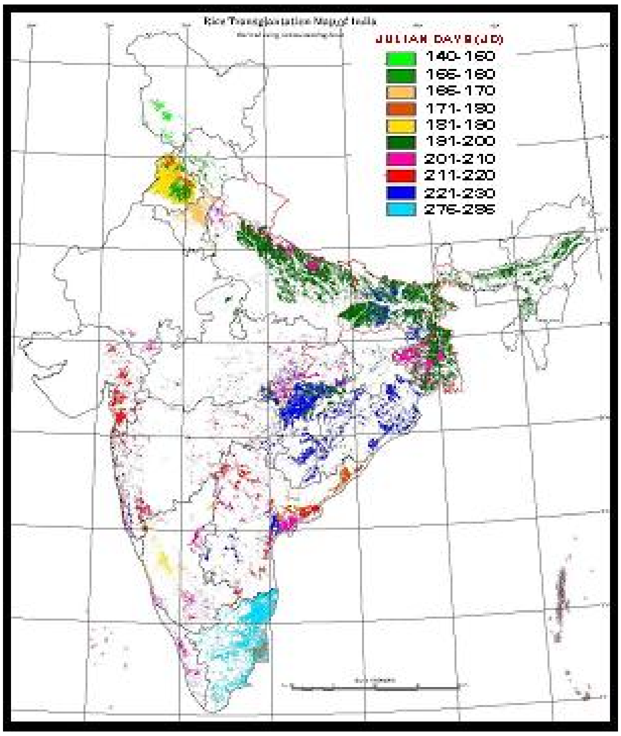

Figure 4. The rice Transplantation Image Derived Using RS Data (Wet Season)

CONCLUSION

The rice-system is vulnerable in the context of climate change apart from being accredited as major source of anthropogenic methane emission. The current remote sensing study has resulted in generation of seasonal rice maps and rice crop dynamics. The initial results using the 10-day composite of SPOT VGT data has given promising results. Multidate SPOT VGT 10-day composite normalised difference vegetation index data is used along with RADARSAT SAR and IRS WiFS data to map the rice area and generate seasonal rice cropping pattern and crop calendar. The results showed that there are two major rice cropping pattern; wet season and dry season. The wet season rice calendar varied significantly while less variation was observed during dry season Out of 43 Mha of total rice lands, wet season occupied 88.8 per cent. The average crop duration of wet rice crop was more than dry season rice by 17 days.

The rice crop is the major food crop of India now with about 44 million ha under cultivation. With the availability of the hybrid short duration, photoperiod insensitive varieties, the crop is now cultivated all the year round at some part or other in the country and thus, the crop calendar vary widely even with in a state. Thus, deriving the rice cropping pattern require very high temporal resolution data. The high temporal SPOT VGT data was able to capture the dynamics of rice planting that varied widely both in the wet and dry season. While a complete quality assessment in terms of crop calendar has yet to be done, the results indicate the potential of the data to study state and region level crop dynamics, cropping pattern and crop rotation. The spatial data base of rice cropping pattern and crop calendar of India has been generated, which will serve as baseline data for relevant simulation studies on climate change and green house gas emission.

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