AN ACCOUNT OF RESIDUE BURNING FROM AGRICULTURAL SYSTEM IN INDIA USING SPACE BASED OBSERVATIONS

C.P. Singh* and S. Panigrahy

AFEG/RESA, Space Applications Centre (ISRO), Satellite Road, Ahmedabad, Gujarat, India

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ABSTRACT:

One of the major sources of emission of green house gases (GHGs) is biomass burning. Thus the space-based observations of global distribution of fire form a key component of climate change studies. Several international programs have been established towards the goal of gaining complete information on fire activity around the world using space based observations. This study mainly highlights the spatio-temporal occurrence of agricultural residues burning in Indo-Gangetic plains of India using fire products from space borne satellites. The 3 years daily active fire data from MODIS (Aqua/Terra) have been used from August, 2006 to July, 2009. The data analysis showed that out of total fire events, around 69% contribution comes from agricultural areas and remaining (31%) comes from non-agricultural areas. This is mainly due to the intensive cultivation happening in this belt. It has also been found that, 84% of agriculture residues burning is from Rice-Wheat system (RWS) and remaining 16% in other types of crop rotations. The fire incidents are reported very high in October-December (55%) compared to that in March-May (36%), indicating that burning of rice residue is more prevalent than that of wheat. This paper highlights some of these facts to understand the agriculture residue burning scenario in relation to agriculture practice as a basic fact sheet and as a step towards mitigation planning.

1. INTRODUCTION

1.1 Agriculture Residue Burning

Two notable components of biomass burning are the incineration of wood, charcoal and agriculture waste as household fuel, and the combustion of crop residue in open fields. Agriculture residue includes all leaves, straw and husks left in the field after harvest. Agricultural fires are generally controlled fire events as compared to forest fires, but needs proper monitoring due to ambient air quality issues.

The single largest category of crops is cereals. The waste products which are the main contributors to biomass burning are wheat residue, rice straw and hulls, barley residue, maize stalks and leaves, and millet and sorghum stalks. Sugar cane also provides the next sizeable residue with two major crop wastes: barbojo, or the leaves and stalk, and bagasse, the crop processing residue. The cotton crop also gives nonnegligible residue in the form of stalks and husks, both of which are used as biofuels (Rosemarie and Jennifer, 2003).

1.2 Rice-Wheat-System (RWS) in Indo-Gangetic Plains (IGP)

Rice (*Oriza sativa*)–wheat (*Triticum aestivum*) cropping system has a long history in India. In the Indian subcontinent, states like Uttar Pradesh (U.P.) have practised this cropping system since 1872, and Punjab (Pakistan and India) and Bengal (India and Bangladesh) since 1920 (Pal *et al*, 2002). RWS occupies nearly one-fifth of the total area under these crops (Hobbs and Morris, 2002). The region is named Indo-Gangetic Plains after the Indus and the Ganges, the twin rivers that drain it. The RWS in the IGP spans from the Swat valley in Pakistan through the States of Punjab, Haryana, UP, Bihar and West Bengal in India, and into Nepal and Bangladesh. The IGP occupies one-sixth of South Asia's geographical area, holds nearly 42% of its total population and produces more than 45% of its food (Janaiah and Hossain, 2003). Nearly 85% of the RWS of South Asia is located in the IGP. Other parts of the RWS outside IGP lie in Madhya Pradesh (MP), Himachal Pradesh (HP), Brahmaputra flood plains of Assam and southwestern parts of India and Bangladesh. The total area under RWS in India is roughly around 20 m ha. Almost 90–95% of the rice area in Punjab, Haryana and western UP is used under intensive RWS (Ladha *et al*, 2000, Janaiah, and Hossain, 2003). Northwestern part of the IGP has about 75% of the cropped area under combine harvesting (Gupta *et al.*, 2003), which is about 15 m ha. It was estimated that during year 2000 about 78 and 85 million tons dry rice and wheat straw were generated in India alone, of which about 17 and 19 million tons may end up in field-burning respectively (Gupta *et al.*, 2004).

The major limitation of the RWS is the short time available between rice harvesting and plantation of wheat, and any delay in planting adversely affects the wheat crop. Preparation of the field also involves removal of rice straw left in the field. This has led to the introduction of mechanized harvesting technologies to enhance efficiency and save time. Among the various harvesters introduced, combine mechanized harvesters are most popular in RWS. The residue generated in general are utilized mainly as industrial/domestic fuel, fodder for animals, packaging, bedding, wall construction, in situ incorporation and green manuring, thatching and left in field for open burning. In situ incorporation is not feasible in RWS as the decomposition of residue takes a long time and affects the growth of wheat crop. Thus, for a farmer it is

*cpsingh@sac.isro.gov.in

economical and easier to burn the residue in the field to enable early sowing. Moreover, in case of combine mechanized harvesting almost all the residue generated is left in the field, which finally ends up in burning, because the utilization of it in the short time is again difficult (Gupta, R.K., et al., 2003). In year 2000, the total agricultural residue production in India was 347 million tons, of which rice and wheat straw accounted for more than 200 million tons (Thakur, 2003). For every 4 tons of rice or wheat grain, about 6 tons of straw is produced (Thakur, 2003). Large amount of crop residue is produced from RWS in India from major involved States, viz. Punjab, UP, MP, Bihar, Haryana, Maharashtra, Gujarat and HP.

1.3 Basics and Importance of Space Based Fire Detection

Active fires can be monitored at a very low spatial resolution due to substantial increase in middle infrared (MIR) brightness of a fire pixel over its background (Robinson, 1991). Basically, the mid-infrared part of the spectrum produces a very strong signal in response to high temperatures and this makes it most suitable region for fire detection. This can be explained with the help of Wien's displacement law which states that there exists an inverse relationship between the temperature of a black body and wavelength at which it has its peak emission (Dozier, 1981, Matson and Dozier, 1981). The band at 3.9µm has a strong thermal response even if only a small portion of the pixel is covered by fire and this characteristic is vital for agriculture fire detection.

Fire release a lot of heat, smoke and aerosol particles into the atmosphere, therefore, this makes fire detection very useful for climate modellers (Crutzen *et al*., 1979). The impacts of burning of crop residue on the environment range from harmful emissions to the atmosphere, loss of nutrients and degradation of soil properties to wastage of residue. The problem has become more serious than before, therefore, several international programs have been established towards the goal of gaining complete information on fire activity around the world using satellite sensors. These include the International Geosphere Biosphere Program Data and Information System's (IGBP-DIS), Global fire Product initiative (Justice *et al*, 1996), the world fire web, the ATSR World Fire Atlas (Arino and Rosaz, 1999), the MODIS (Moderate Resolution Imaging Spectro-radiometer) Fire Product (Kaufman *et al*., 1998).

1.4 Algorithms

Fire detection algorithms may be classified in three categories (Kaufman *et al*., 1998): 1). Single channel threshold algorithms, based on only one channel, basically using 3.95µm band of MODIS, 3.75µm (channel 3) of AVHRR or similar channels of other sensors. The most challenging task in using single channel to detect fires during daytime is to account for the influence of solar reflection from cloud and bright surfaces within the limits dictated by the low saturation of 3.95 µm band (Giglio *et al*., 2003). Therefore screening for Clouds and bare surfaces are required to identify potential fires. 2). Multi-channel threshold algorithms generally consist of three basic steps (Kaufman *et al.*, 1998): (i) using channel 3 of AVHRR in identifying all potential fires; (ii) thermal channel 4 of AVHRR to eliminate clouds; and (iii) using the difference between brightness temperature in channels 3 and 4 to isolate fires from warm background. These improvements did not correct for the possible presence of reflective surfaces. The multi-channel threshold algorithms were mainly used in regional or even continental applications like fires in tropical forest (Kaufman *et al*., 1998); fires in savanna and boreal forests (Li *et al*., 2000). To expand the utility of multi-channel algorithms, multi-channel contextual algorithms were proposed (Lee and Tag, 1990). 3). Contextual algorithms compare the potential fire pixel with the thermal properties of the background. This involves two basic steps: initial setting of thresholds to identify potential fire pixels and then fine-tuning the thresholds to confirm fires among the potential fire pixels (Martin *et al*., 1999). The tests in the first step are similar to the multi-channel threshold techniques except that the thresholds are more liberal to avoid missing real fires. The second step computes the mean and standard deviation of the threshold variables from non-potential fire pixels surrounding a potential fire pixel. The window size for computing the means and standard deviations is set in a somewhat ad-hoc manner, varying typically from 3×3 pixels up to 21×21 (Flasse and Ceccato, 1996) until the number of qualified background pixels reaches a pre-specified value. After obtaining these statistics, they are used to re-define the thresholds to confirm a fire. This approach is reported to reduce the false fire alarms (Martin *et al*., 1999). Initially MODIS fire detection algorithm was designed by Kaufman, 1998 which produced persistent false detections over sparsely vegetated land surfaces and relatively small fires were frequently undetected. In an attempt to overcome this issue multi-thresholding contextual algorithm was proposed by Giglio *et al*., 2003. MODIS fire products (MOD14) uses this algorithm (Giglio *et al*., 2003) along with the algorithms that removes false fire alarms caused due by sun glint, water and coastal boundary and desert boundary effects.

This study gives an account of agriculture residue burning in IGP which is related to the rapid rise happening in global temperatures. Scientists attribute the temperature increase to a rise in carbon dioxide (CO_2) and other greenhouse gases released from the burning of fossil fuels, deforestation, agriculture and other industrial processes. The primary greenhouse gases associated with agriculture are CO_2, methane (CH_4) and nitrous oxide (N_20). Agriculture activities serve as both sources and sinks for greenhouse gases. Agriculture sinks of greenhouse gases are reservoirs of carbon that have been removed from the atmosphere through the process of biological carbon sequestration. The primary sources of CO_2 in agriculture are the burning of agriculture residue and combustion of fossil fuels. By employing farming practices that involve minimal disturbance of the soil and encourage carbon sequestration, farmers may be able to minimize the loss of carbon from their fields. Therefore, there is a need to understand the global agriculture fire and associated farming practices towards combating global warming.

1.5 Objectives

The present study aims to use contextual algorithm based fire products (MOD14) to characterise the agriculture residue burning in the states of IGP with the help of remote sensing based crop rotation maps.

2. STUDY AREA

2.1 General Settings

The study area includes five Indian states, namely, Punjab, Haryana, Uttar Pradesh, Bihar, and West Bengal falling in vast Indo-Gangetic Plain (IGP). This has geographical area of 5,71,490 sq. km. It lies between 21^{o}35'–32^{o}28'N latitude. and 73^{o}50'–89^{o}49'E longitude, surrounded by Pakistan to its west, Jammu and Kashmir, Himachal, Uttarakhand to its north, North-eastern states to its east and Rajasthan, Madhya Pradesh,Chattisgarh and Jharkhand to its west (figure 1). Most of the area is a gently undulating plain.

2.2 Geography / Socio-Economic

The Rice-Wheat cropping system is spread in above five IGP states (figure 1). These states are under four agro-climatic regions (ACRs) including: Trans-Gangetic Plain covering Punjab and Haryana (ACR VI); Upper-Gangetic Plain covering western UP (ACR V); Middle-Gangetic Plain covering eastern UP and Bihar (ACR IV); and Lower-Gangetic Plain covering West Bengal (ACR III). The area under RWS in the IGP is about 9 million hectares (M ha). There is an additional 1.5 to 2 M ha outside the IGP in the states of Himachal Pradesh, Uttarakhand, Madhya Pradesh, and Rajasthan (Prasad, 2007).

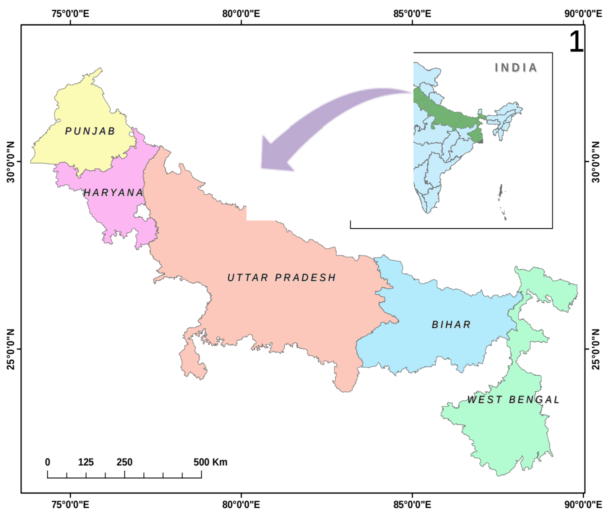

Figure 1. Study Area Map (States of Indo-Gangetic Plain)

This vast agricultural land is supporting about 406 million people (Web1). Two narrow terrain belts, collectively known as the Terai, constitute the northern boundary of the IGP. In the area where foothills of the Himalayas encounter the plain, small hills are formed by coarse sands and pebbles deposited by mountain streams. The southern boundary of the plain begins along the edge of the Great Indian Desert in the state of Rajasthan, before continuing east along the base of the hills of the Central Highlands to the Bay of Bengal. The main source of rainfall is the southwest monsoon which is normally sufficient for general agriculture. The many rivers flowing out of the Himalayas provide water for major irrigation works. The Punjab and Haryana plains are irrigated with water from the Ravi, Beas, and Sutlej rivers. The middle Ganga extends from the Yamuna River in the west to the state of West Bengal. Farming on the IGP primarily consists of rice and wheat grown in rotation. Other crops include maize, sugarcane and cotton (figure 2).

3. MATERIAL AND METHODS

3.1 Data Used

Data Product	Satellites/ Sensors used	Spatial Resolution	Time Period
MOD14*	(Terra/Aqua)/ MODIS	1 km	Daily fire of 3 years (August, 2006 to July, 2009)
Crop-rotation**	SPOT-VGT	1 km	Year 2002-03

Table 1: Shows the List of Data Used for this Stud\y

*Table 1: List of Data Used [Source: * MODIS fire information system, Geoinformatics center, Asian Institute of Technology, Thailand ** Panigrahy et al, 2009]*

3.2 Methodology

Daily MODIS fire products (MOD14) were downloaded for the study period (table 1) from both the Terra and Aqua platforms for day and night acquisitions in ASCII format. The data is having Time, Day / Night tag, Satellite platform tag, Latitude, Longitude, Reflectance of Band2, Brightness Temperature of Band 21 & Band 31, Fire power and Fire confidence.

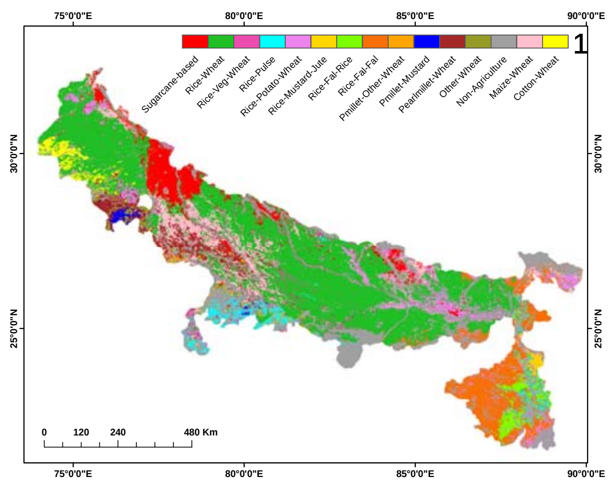

Figure 2. Crop-rotation Map of the Study Area (Source Panigrahy et al., 2009)

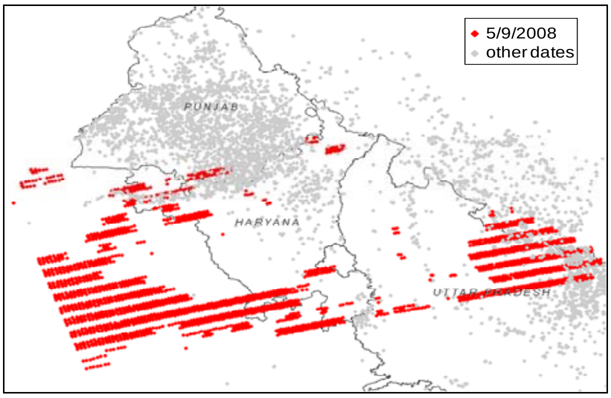

Figure 3. Identification of False Fire Alarms Pertaining to September 5, 2008 of Terra Platform (Night time)

The ASCII data was converted to comma separated values (CSV) and based on the mapping of the latitude and longitude fields in ArcGIS these points were converted to GIS ready vector format (.SHP files). It was found that night time data from Terra platform pertaining to September 5, 2008 having reflectance value of band 2 as -1 was not reliable (figure 3) and therefore omitted from the data analysis. In the global MOD14 algorithm, drop in band 2 reflectance is also used to detect candidate changes associated with burning. But, this drop in reflectance may be due to shadows, cast by clouds and surface relief and so exhibit similar spectral changes as those caused by fire (Roy *et al*. 2002, Justice *et al*., 2006). The remaining point vector files were extracted for the IGP area using a mask of the IGP state's administrative boundary. The fire point data was overlaid on the crop-rotation image (Panigrahy *et al*, 2009) and the raster values were transferred to the point coverage for further analysis.

4. RESULTS

4.1 Fire Events Observed in Different Cropping System

To know the likely crop residue being burnt in the study area the crop rotation data (figure 2) was used. This crop rotation data was overlaid with the fire location point vector file generated by the fire detection algorithm and the majority class of cropping system that is falling within the fire location cluster was extracted. The data analysis showed that out of total fire events, around 69% contribution comes from agricultural areas and remaining (31%) comes from non-agricultural (forest and bush) fire. The result also shows that out of total agriculture based burnings, 84% were in the rice-wheat and rice-other crop-wheat based cropping systems or RWS (figure 4). Fire events were also detected in the Cotton-Wheat (2%), Maize-Wheat (3%), Pearlmillet-Wheat (1%), Rice-Fallow-Fallow (5%), and Sugarcane-based cropping systems (4%). However, RWS is known for residue burning practice, the other cropping patterns showing small fire activities may also be due to the saturation caused by small fraction of the pixels (Justice *et al*., 2006) where rice is being cultivated.

4.2 Characterisation of Agriculture Fire

The total fire events detected (including non-agricultural areas) were 8,726 with contribution from agricultural being 69%. Analysis also showed that the fire events were mainly confined to the months of March – May (36%) and October- December (55%) (Table 2). In the first part, April shows the highest fire events with 18.25% and the in the second part, October shows the highest fire events with 45.59% out of total agricultural fire in the study area. This is due to the burning of leftover crop residues of rice crop before planting of rabi season crop (Milap *et al*., 2008). The fact is that, the time-gap available for planting rice is quite high and therefore the farmer may wait for rainfall to get the residues naturally decomposed. On the contrary, the time gap available between rice to wheat cropping is not sufficient for nutrient enrichment, the reason for higher rice residues being burned in the agricultural fields during October to November.

States	CR	Months												Grand Total
		J	F	M	A	M	J	J	A	S	O	N	D	
Bihar	MW	1	4		5	5		1				1		17
	PW	1											1	2
	RFF	2	3	4	1		1			1				12
	RPW	5	13	14	43	12	2	2	3		1	3	9	107
	RW	2	9	4	278	26	12	1			1	21	131	485
	SB	2	7	4	3	2	1							19
Total		13	36	26	330	45	16	4	3	1	2	25	141	642
Haryana	CW					3		1			7			11
	MW			1	1						2			4
	OW				2			1						3
	PW					5		1	1	1				8
	PM								1					1
	RPW			1	4	8					24		1	38
	RW				63	110				8	381	9	1	572
	SB			1	5	8					7			21
Total				3	75	134		3	2	9	421	9	2	658
Punjab	CW				2	15					96			113
	MW				1	2					54	1		58
	OW										1			1
	RPW					2					27			29
	RW				30	151	1			1	1999	100	2	2284
	SB				1	3					19			23
Total					34	173	1			1	2196	101	2	2508
Uttar Pradesh	CW				1									1
	MW	11	4	3	19	24	2	1		2	15	15	10	106
	PW	7	13	1	7	13	1				6	8	13	69
	PM							1						1
	POW				2	2				2	1			7
	RPW	2	2	5	57	13	1		1	2	1	1	2	87
	RP	2	3		1		1	1	1				1	10
	RVW	2	7	4	6	4	1			1	2	2	4	33
	RW	51	80	64	502	332	11	3	2	8	95	113	94	1355
	SB	5	25	31	38	43				5	4	3	11	165
Total		80	134	108	633	431	17	6	4	20	124	142	135	1834
West Bengal	MW	1		6	1	2								10
	RFF	19	80	125	18	3	25	3	7	5	1	2	15	303
	RFR				1		2						1	4
	RMJ	1			6									7
	RPW	7	6	11	1	6	5		4	5	3	3	2	53
	RP				1	1	3							5
	RW	1										1		2
Total		29	86	142	28	12	35	3	11	10	4	6	18	384
Grand Total		122	256	279	1100	795	69	16	20	41	2747	283	298	**6026**

Table 2: Cumulative Monthly Fire Counts in IGP States

[CR: Crop Rotation; MW: Maize-Wheat; PW: Pearlmillet-Wheat; RFF: Rice-Fallow-Fallow; RPW: Rice-Potato-Wheat; RW: Rice-Wheat; SB: Sugarcane-based; CW: Cotton-Wheat; OW: Other-Wheat; PM: Pmillet-Mustard; POW: Pmillet-Other-Wheat; RP:

Rice-Pulse; RVW: Rice-Veg-Wheat; RFR: Rice-Fallow-Rice; RMJ: Rice-Mustard-Jute]

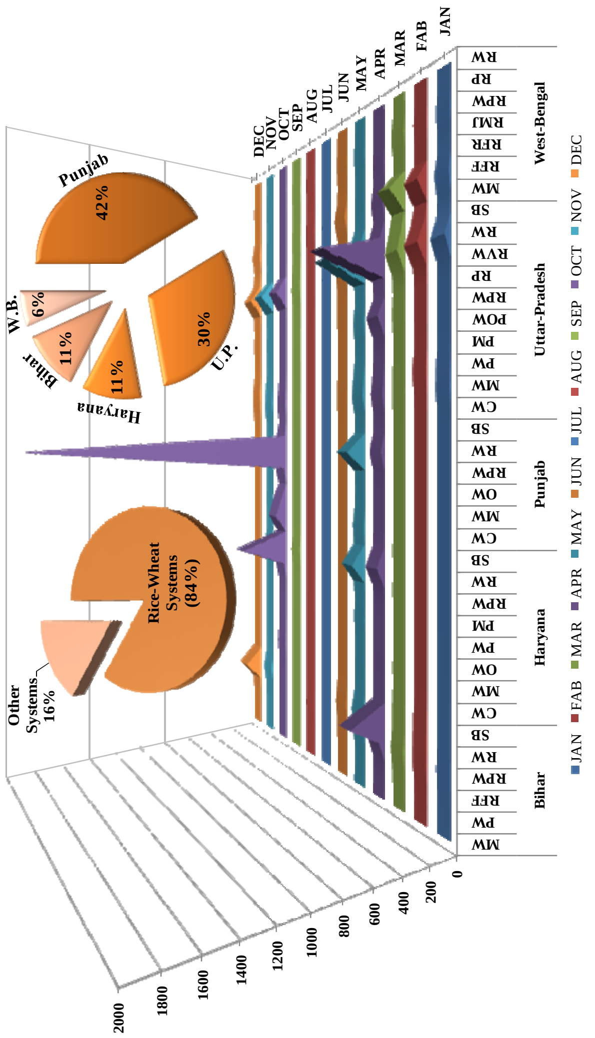

Figure 4. Aggregate Monthly, Crop-Rotation Wise Agriculture Residue Burning for Indo-Gangetic Plain States and Percentage Contribution of Individual States

5. DISCUSSION AND CONCLUSION

Rice is grown during warm, humid season between June and October and wheat in cool, dry season between November and March. There is little time available between harvesting of rice and planting of wheat and moreover, performance of wheat crop is highly susceptible to any delay in planting. This has resulted in mechanizations of harvesting in RWS and introduction of combine harvesters. Due to the use of combine harvesters, there has been a sharp increase in the share of open field burning as it leaves behind large quantities of agricultural residues (Gupta, R.K., *et al*., 2003). It is very clear from the figure 4, that agricultural residue burning is more serious in the state of Punjab. It has been reported by Milap *et al*., 2008 that, in Punjab, this is mainly due to burning of crop residue before sowing of rabi season crop. Moreover, Punjab has about 2.647 m ha under paddy cultivation that yields roughly 100 million tones of rice straw and about three-fourth of crop residue is disposed off by burning (Badrinath *et al.*, 2006). The emission of CH_4, CO and N_2O has been estimated to be about 110, 2306, and 2 Gg respectively, in 2000 from rice and wheat straw burning in India (Gupta *et al*., 2004). Residue burning also causes nutrient and resource loss, and reduces total N and C in the topsoil layer, thus calling for improvement in harvesting technologies and sustainable management of the RWS (Gupta, *et al*., 2003).

The fire events in Punjab are detected in the Months of April – May and October- November only. During April and May, basically the Wheat residues are being burned and during October and November, the Rice residues are being burned. The burning of Wheat residues is quite less (8%) during April-May in comparison to burning of Rice residues (92%) during October-November in Punjab (table 2). This is because of the fact that the time-gap available for planting Rice is quite high and therefore the farmer may wait for rainfall to get the residues naturally leaves its nutrients to soil. The time gap available between rice to wheat cropping is not sufficient for nutrient enrichment, the reason for higher rice residues being burned in the agricultural fields. Still, *In situ* incorporation being the best option may be further investigated for fast decomposition of residue.

Agricultural fire detection in the near real time is very essential as it can help in preventing crop loss if the fire incidences occur before the harvest of the crop. The uncontrolled and badly chosen time of burning of residues generally causes pollution in the ambient air and deteriorates the quality of air we breathe. The associated health hazards are well known. Therefore, the meteorological parameters should be considered and the authorities should inform farmers about a proper time window for controlled burning, so that the gases goes straight to the upper atmosphere and should not cause health hazard by concentrating in ambient air. Burning of crop residue results in emission of trace gases and particulate matters, loss of plant nutrients and thus adversely affects the pedology.

Burning of agricultural residue is now recognized as an important source of pollutant emissions. It leads to emission of trace gases like CH_4, CO, N_2O, NOx, SO_2, and hydrocarbons. Burning of straw also emits large amount of particulates that are composed of a wide variety of organic and inorganic species. One tonne straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_2. These gases and aerosols consisting of carbonaceous matter have an important role to play in the atmospheric chemistry and can affect regional environment, which also has linkages with global climate change (Gupta *et al*., 2004). The future Indian mission, INSAT-3D having capability to detect fire at every 30 minutes will enhance the capability of such active fire detection from space and will be able to provide more realistic picture of short lived fire events in RWS.

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REFERENCES

Arino, O., and Rosaz, J.M., 1999. World ATSR Fire Atlas using ERS-2 ATSR-2 Data. Proceedings of the Joint Fire Science Conference, Boise, pp. 15–17.

Badrinath, K.V.S. and Kiran Chand, T.R., 2006. Agriculture crop residue burning in the Indo-Gangetic Plains – A study using IRSP6 WiFS satellite data. *Current Science*, 91 pp. 1085–1089.

Crutzen, P.J., Heidt, L.E., Krasnec, J.P., Pollock, W.H., and W. Seiler, W., 1979. Biomass burning as a source of atmospheric gases, CO, H_2O, N_2O, NO, CH_3CL and COS, *Nature*, 282 pp. 253-256.

Dozier, J., 1981. A method for satellite identification of surface temperature fields of subpixel resolution. *Remote Sensing of Environment*, 11 pp. 221–229.

Flasse, S.P., and Ceccato, P., 1996. A contextual algorithm for AVHRR fire detection, *International Journal for Remote Sensing*, 17 pp. 419–424.

Giglio L., Descloitres. J., Justice. C.O., Koufman. Y.J., 2003. An enhanced contextual fire detection algorithm for MODIS. *Remote sensing of Environment*, 87 pp. 273–282.

Gupta, P.K., Sahai, S., Singh, N., Dixit, C.K., Singh, D.P., Sharma, C., Tiwari, M.K., Gupta, R.K., Garg, S. C., 2004. Residue burning in rice–wheat cropping system: Causes and implications. *Current Science*, 87 pp. 1713–1715.

Gupta, R.K., Naresh, R.K., Hobbs, P.R., Jiaguo, Z. and Ladha, J. K., 2003. Sustainability of post-green revolution agriculture: The rice– wheat cropping systems of the Indo-Gangetic Plains and China. In Improving the Productivity and Sustainability of Rice–Wheat System: Issues and Impacts, ASA Special Publication 65, Wisconsin, USA.

Hobbs, P.R. and Morris, M.L., 2002, Meetings South Asia's future food requirements from rice–wheat cropping systems; priorities issues facing researchers in the post green revolution era. NRG Paper 96–01. CIMMYT, Mexico, D.F.

Janaiah, A. and Hossain, M., 2003, Farm-level sustainability of intensive rice–wheat system: socio-economic and policy perspectives. *Addressing Resource Conservation Issues in Rice–Wheat Systems of South Asia, A Resource Book*, Rice Wheat Consortium for Indo-Gangetic Plains (CIMMYT).

Justice C., Giglio L., Boschetti L., Roy D., Csiszar I., Morisette J., and Kaufman Y., 2006. MODIS fire products algorithm and theoretical document. EOS ID# 2741, Ver. 2.3

Justice, C., Malingreau, J.P., and Setzer,A.W., 1996. Remote sensing of fires: Potential and limitations, Fire in the Environment (P.J. Crutzen and J.G. Goldammer, Eds.), pp. 77–88.

Kaufman Y.J., Justice O.P., Flynn L.P., Kendall J.D., Prins E.M., Giglio. L., Ward D.E., Menzel W.P and Setzer A.W., 1998. Potential Global Fire Monitoring from EOS-MODIS. Journal of Geophysical Research, 103 pp. 32215–32238.

Ladha, J.K., Fischer, K.S., Hossan, M., Hobbs P.R. and Hardy, B. (eds), 2000, Improving the productivity and sustainability of rice–wheat systems of the Indo-Gangetic plains: A synthesis of NARS–IRRI partnership research. IRRI Discussion Paper Ser. 40, IRRI, Los Banos, Philippines.

Lee T.M., and Tag P. M., 1990. Improved detection of hotspots using the AVHRR 3.7 µm channel. Bull. Amer. Meteoro. Soc. 71 pp. 1722–1730.

Li, Z., Nadon, S., & Cihlar, A.J., 2000. Satellite-based detection of Canadian boreal forest fires: development and application of the algorithm. *International Journal of Remote Sensing*, 21 pp. 3057–3069.

Martin, P., Ceccato, P., Flasse, S., and Downey, 1999. I. Fire detection and fire growth monitoring using satellite data. Remote Sensing of Large Wildfires in the European Mediterranean Basin, Chuvieco, E., (Ed.). Springer-Verlag Berlin/Heidelberg 3–540–65767–3, 12, 212.

Matson, M., and Dozier, J., 1981. Identification of sub resolution high temperature sources using a thermal infra red sensor. *Photogrammetric Engineering and Remote Sensing*, 47 pp. 1311–1318.

Milap, P., Vinod P.N., Yogesh K., 2008. Identifying biomass burned patches of agriculture residue using satellite remote sensing data. *Current Science*, 94(9) pp. 1185–1190.

Pal, S.S., Jat, M.L., Sharma, S.K. and Yadav, R.L., Project Directorate for Cropping System Research, ICAR, Modipuram, Meerut, 2002.

Panigrahy S., Upadhyay, G., Ray, S.S., Parihar, J.S., 2009, Mapping of cropping system for the Indo-gangetic plain using multidate SPOT- NDVI-VGT data, submitted to *Jr. of Indian Soc. of Remote sensing*.

Prasad, R., 2007, Phosphorus Management in the Rice-Wheat Cropping System of the Indo-Gangetic Plains, Better Crops – India, pp.8-11 (http://www.ppi-ppic.org/ppiweb/bc-india.nsf/$webindex/A03A89DF68C02F6B852573830055FD12/$file/bc-india_Nov07_p08.pdf) (accessed 23 Oct. 2009)

Robinson J.M., 1991. Fire from Space: Global fire evaluation using infrared remote sensing. *International Journal of Remote Sensing*, 12 (1) pp. 3–24.

Rosemarie, Y., and Jennifer A.L., 2003. An assessment of biofuel use and burning of agricultural waste in the developing world, *Global Biogeochemical Cycles*, Vol. 17, No. 4, 1095, pp.6-(1–21)

Roy, D., Borak, J, Devadiga, S., Wolfe, R., Zheng, M., Descloitres, J., 2002, The MODIS land product quality assessment approach, *Remote Sensing of Environment*, 83:62–76.

Thakur, T.C., 2003, Crop residue as animal feed. *Addressing Resource Conservation Issues in Rice–Wheat Systems of South Asia, A Resource Book*. Rice Wheat Consortium for Indo-Gangetic Plains (CIMMYT)

Web1: http://mha.nic.in (ministry of home affairs, GOI) (accessed 21 Oct. 2009)