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Agriculture crop residue burning in the Indo-Gangetic Plains – A study using IRS-P6 AWiFS satellite data

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Biomass burning from forest regions and agriculture crop residues can emit substantial amounts of particulate matter and other pollutants into the atmosphere. An inventory of forest, grassland and agricultural burning is important for studies related to global change. This study provides an account of the agriculture crop residue burning in Punjab during wheat and rice crop growing periods. Indian Remote Sensing Satellite (IRS-P6) Advanced Wide Field Sensor (AWiFS) data during May and October 2005 have been analysed for estimating the extent of burnt areas and thereby greenhouse gas (GHG) emissions from crop residue burning. Emission factors available in the literature were integrated with satellite remote sensing data for estimating the emissions. Results suggested that emissions from wheat crop residues in Punjab are relatively low compared to those from paddy fields. It is inferred that incorporation of agricultural residues into the soil in rice–wheat systems is highly sustainable and eco-friendly, rather than burning the crop residues. The potential of satellite remote sensing datasets for burnt area estimation and GHG emissions, is also demonstrated in the study.

Keywords: Biomass burning, cereal waste, gases and particle emissions, field burning, global change.

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THERE has been substantial increase in the area sown to rice–wheat (R–W) in South and East Asia, made possible by the development of short-duration cultivars of both species and the expansion of irrigation. R–W systems extend across the Indo-Gangetic Plains (IGP) into the Himalayan foothills, spanning a vast area from Pakistan's Swat Valley in the north to India's Maharashtra State in the south, and from the mountainous Hindu Kush of Afghanistan in the west to the Brahmaputra floodplains of Bangladesh in the east. The IGP is composed of the Indus (areas in Pakistan, and parts of Punjab and Haryana in India) and the Gangetic Plains (Uttar Pradesh (UP), Bihar, and West Bengal in India, Nepal and Bangladesh). The Indus Plains component of the IGP has experienced increasing levels of farm mechanization over the last 20 years. Cultivation for seed-bed preparation and harvesting in particular, is now commonly undertaken with farm machinery. Even growers with small landholdings have access to local contractors who provide mechanized services for these operations. Wheat residue after grain harvest is valued highly for animal feed and therefore presents no difficulty in terms of management for it is largely removed. Rice residues, on the other hand, can be large and are generally not used for animal feed (except Basmati rice). Consequently, rice residues are usually burnt to enable tillage and seeding machinery to work effectively. This large-scale burning of rice residue is a major source of trace gases along with sub-micron sized aerosols, which are known to aggravate lung and respiratory diseases[1]. Agricultural intensification in Punjab is an inevitable consequence of the increasing population pressure and decreasing per capita land area. In the IGP region of India, nearly 12 million hectares is accounted for rice–wheat rotation. Harvesting of these crops with combine harvesters is popular with farmers of Punjab, Haryana and western UP on account of high labour wages and anxiety of the farmers to get the crop produce collected and marketed at the earliest. Tentative estimates show that in Punjab 75–80% under rice is machine-harvested, which leaves behind enormous quantities of organic matter. Residue burning in the R–W systems due to the use of combines has resulted in pollutant emission, loss of nutrients, diminished soil biota, and reduced total N and C in the topsoil layer. In earlier studies, tentative gaseous emissions have been estimated to be 110, 2306, 2 and 84 Gg respectively, for CH_4, CO, N_2O and NO_x from rice and wheat straw burning in India in 2000, which is a noticeable increase in comparison to 1994 (ref. 2). Wheat straw is mainly used as animal feed, whereas rice straw is inferior in feeding quality and hardly used for fodder, at least in Punjab. At present three-fourths of the crop residue amounting to 70 to 80 million tons of rice is disposed-off by burning. The potential of rice residue and its management options, its effects on soil properties and crop productivity have been presented in detail in earlier studies[3]. Crop residue, a renewable resource, is an important component in ecosystem stability of the world's agricultural land. Developing techniques for effective utilization of this vast resource is a major challenge. Almost all the leading newspapers of northern India published reports on the incidence of a thick cloud of smog that enveloped many parts of Punjab and Haryana on 15 October 2005. People experienced reduced visibility, besides irritation in the eyes and throat. This smog was attributed to the large-scale burning of rice straw by farmers[4]. The burning of the residue is not only a source of atmospheric pollution, but also leads to loss of rich renewable soil rejuvenating organic resource. Farmers opt for burning as it is a quick and easy approach for disposal of residue and enables farmers to plant the next wheat crop well on time. This is the primary reason for burning rather than incorporating the same for soil enrichment. The objective of the present study is to infer the extent of crop residue-burnt areas using satellite data during rice/wheat cropping seasons and estimating emissions from such burning practices.

Punjab, situated in northwest India between 29°30′–32°32″N and 73°55′–76°50″E, occupies 50,362 sq. km, i.e. 1.54% of India's total geographical area (Figure 1). Punjab, located between the Indus and Ganges rivers, is largely an alluvial plain irrigated by canals. Its arid southern border edges the Thar or Great Indian Desert. The Shivalik Ranges rise majestically in the north. Four rivers, i.e. Ravi, Beas, Satluj and Ghaggar flow across the State in the southwest direction. Several small seasonal tributaries branch out from these rivers. At present, over 84% of the total geographical area of the State stands cultivated. Only about 28,000 ha land is classified as cultivable waste. The State looks like a vast farmstead with only 16% of its geographical area under cities, towns, villages, rivers, canals, roads, buildings, wastes, forests, etc. Thus, there is little scope for horizontal expansion of crop cultivation. Vertically, the intensity of cropping is over 186%. The major crops in the State are wheat, maize (corn), rice, pulses (legumes), sugarcane, cotton, exotic vegetables. Average annual rainfall of the State is 462.8 mm and over 70% of the annual rainfall occurs during the monsoon season, i.e. from July to September.

IRS-P6 Advanced Wide Field Sensor (AWiFS) data of 14 May 2005 and 10 October 2005 were analysed for estimating the agriculture crop residue burnt areas in Punjab. AWiFS sensor consists of four spectral bands with 56 m spatial resolution and covers a wide swath of ~ 740 km on ground (Table 1). Satellite datasets were registered to reference image having Lambert Conformal Conic projection and have been classified using maximum likelihood classifier for obtaining information on agriculture burnt areas. The training areas of burnt areas were provided in the digital classification approach by taking the number of samples scattered across the image. Classification accuracy was estimated using digital methods by computing the confusion matrix, which is a measure of overlap between neighbouring classes. The accuracy of the training classes is more than 99% and the overall mapping accuracy has been estimated to be around 90%.

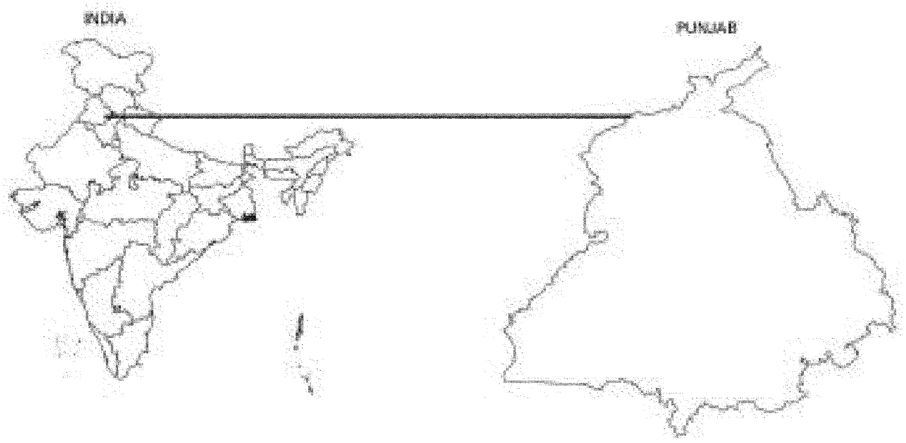

Figure 1. Study area.

Table 1. AWiFS sensor characteristics on-board IRS-P6 (RESOURCE-SAT-1)

Parameter/instrument	AWiFS
Spatial resolution or IFOV (Instantaneous Field of View)	56 m (nadir) (70 m a swath edge)
Spectral bands (μm)	B2: 0.52–0.59 (green) B3: 0.62–0.68 (red) B4: 0.77–0.86 (NIR) B5: 1.55–1.70 (SWIR)
Swath width	740 km
Data quantization	10 bit
Data rate	52.5 Mbit/s

Emissions from agriculture burnt areas were estimated by applying the following expression:

Emissions (g) = Emission factor (g/ton) × Fuel consumption (tons/ha) × Area burned (ha).

IRS-P6 AWiFS data were used for estimating acreage of crop residue burnt area and emission factors were drawn from the literature[1,5–9]. IRS-P6 AWiFS sensor with short-wave infrared band provides clear separability of burnt areas with accuracy better than 90%. Although the emission factors cited in the literature provide conservative estimates, we infer that several field-level experiments are needed for quantifying greenhouse gas (GHG) emissions from agricultural residue burning in the Indian region.

Figure 2 *a* shows the false colour composite of IRS-P6 AWIFS infrared (0.77–0.86 μm), red (0.62–0.68 μm) and green (0.52–0.59 μm) bands of the study area along with active fires observed at various locations on 14 May 2005. Spatial patterns in fire counts clearly suggest vast spread of agriculture fires in the northern regions of the State on 14 May 2005, coinciding with local reports[4]. The burnt agriculture patches were clearly discernable in AWIFS datasets. Figure 2 *b* shows the classified image of Punjab State and spatial spread of agriculture burnt areas can be clearly noticed from the image in pink colour. The burnt area statistics derived from AWiFS data suggested nearly 5504 sq. km of wheat crop area as burnt during May 2005. The average biomass left in the wheat field after harvesting[3,7] is about 5.94 t/ha. Since emission factors (EFs) for residue burning from the R–W cropping system are absent, in this study we compiled the EFs from similar systems reported elsewhere[5,6]. Using these biomass values and EFs, biomass burning emissions have been estimated for the entire Punjab region. EFs for wheat residue burning were taken[5,6] as EF-CO, 34.66 g/kg; EF–NO_x 2.63 g/kg; EF–CH_4 0.41 g/kg; EF–PM_{10} 3.99 g/kg; EF–$PM_{2.5}$ 3.76 g/kg. The calculated total emissions from Punjab State suggest that wheat crop residue burning contributes about 113 Gg of CO, 8.6 Gg of NO_x, 1.33 Gg of CH_4, 13 Gg PM_{10} and 12 Gg of $PM_{2.5}$ during May 2005. Figure 2 *c* shows the agriculture crop burnt areas on 10 October 2005. The extent of paddy crop residue burning has been estimated to be 12,685 sq. km, which is much higher than the wheat crop residue burning that occurs during May each year. Emissions from paddy fields burning were estimated to be 261 Gg of CO, 19.8 Gg of NO_x, 3 Gg of CH_4, 30 Gg of PM_{10} and 28.3 Gg of $PM_{2.5}$ during October 2005.

The above emissions have several atmospheric, biospheric and ecological implications. Since the R–W cropping system is practised on a large scale (of about 9.6×10^6 ha in India), pollutants from agricultural residue burning are substantial. Although crop residue yields vary for each crop depending on genotype and environmental factors, dry fodder yield of wheat is estimated[3] to be about 3.2–5.6 t ha^{-1} and rice about 6.2–11.8 t/ha. These high amounts of residues from the R–W agro ecosystems when burnt, form an important source of GHGs, in the Indian region. Considering these implications, agriculture residue burning is one of the major areas, where GHG mitigation options can be focused upon. For the agriculture sector in general, three major

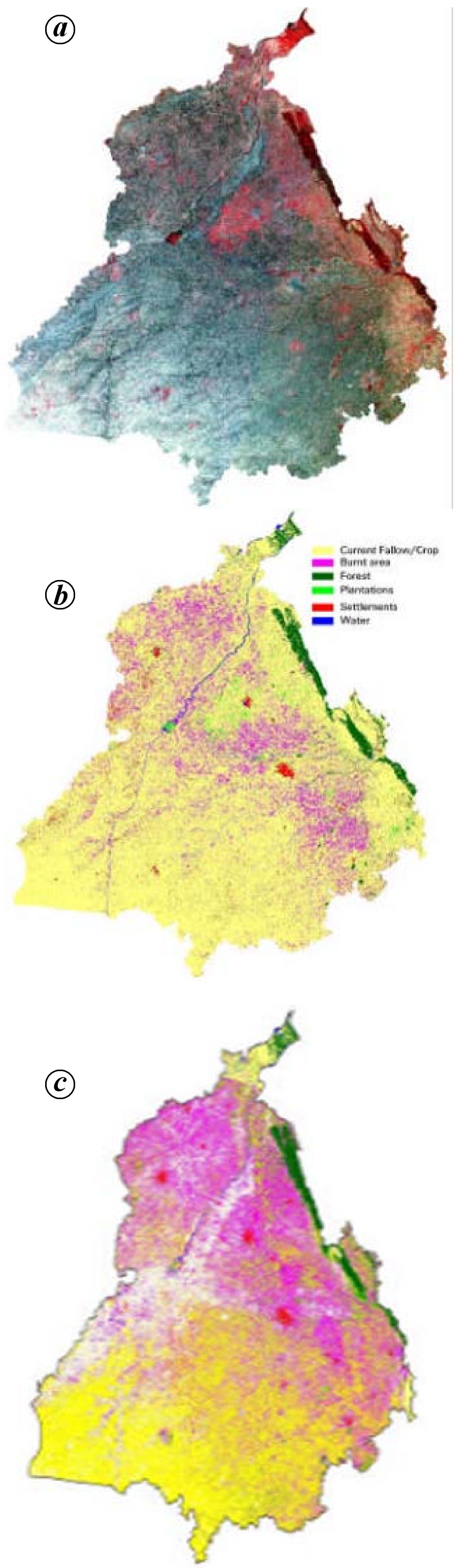

Figure 2. IRS-P6 AWiFS data of 14 May 2005 (***a***) 14 May 2005 classified image (***b***) 10 October 2005 classified image (***c***).

mechanisms by which positive actions can be taken by farmers for reducing or avoiding emissions and increasing sinks in agricultural systems were identified. These include: (i) increasing carbon sinks in soil organic matter and above ground biomass; (ii) avoiding carbon dioxide or other GHG emissions from farms by reducing direct and indirect energy use and (iii) increasing renewable energy production from biomass that either substitutes consumption of fossil fuels or replaces inefficient burning of fuel wood or crop residues, and thus avoids carbon emissions. Specifically, in R–W systems, residue removal and excessive tillage often leads to a decline in several soil properties, in particular, organic matter content. These two practices can result in reductions in water availability and low soil fertility; both responsible for decreased grain yield and crop productivity[1,10]. Among the several methods, incorporation of rice or wheat residue in the soil has been considered a safe and eco-friendly practice rather than agricultural residue burning[7–9,11]. Also, incorporation of residues in the soil has been shown to improve soil fertility without any adverse affects in the long run, i.e. after a number of seasons of residue addition, particularly in combination with fertilizers[2]. Thus, for the R–W cropping system, incorporating crop residues in the soil seems to be one of the major mitigation options for increasing organic matter content and for avoiding GHG emissions from residue burning[1].

IRS-P6 AWiFS satellite data of Punjab State, India have been analysed to study the nature and extent of agriculture residue burning in two different crop-growing periods. The results of the study suggest that AWiFS data with bands in the short-wave infrared could pickup active fires in agriculture areas and derive information on extent of agriculture crop residue burning in fields. Nearly 5504 sq. km area has been estimated to be under wheat crop residue burning and 12,685 sq. km under rice crop residue burning, resulting in the release of several GHG emissions. The emission estimates can be further fine-tuned with field experimentation to arrive at reasonable estimates on emissions. Satellite data together with ground experiments can be effectively used to estimate emissions from agriculture residue burning in different zones of India. Amongst the several mitigation options, incorporation of agricultural residues into the soil in R–W systems seems to be the best strategy, rather than burning of residues.

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Embryonic development in *Octopus aegina* Gray, 1849

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Cephalopods occur in all marine habits of the world. They are extremely important in ecological, biological and biomedical research. The genus *Octopus* consists of more than 100 species and along with *Sepia* sp. and *Sepiella* sp. accounts for about 50% of all described cephalopods. Octopus earns valuable foreign exchange for the country. Knowledge on the embryonic and larval development is essential for hatchery and culture techniques. Development stages of the embryo were sequenced based on morphological characters. During the course of development, the embryo reverses its position two times; the new born resembles adults in form except for its free-swimming mode of life. The gestation period of the embryo was 18 to 20 days at a temperature range of 28–30°C.

Keywords: Egg index, embryonic development, hatchlings, *Octopus aegina*.

IN the phylum Mollusca, class Cephalopoda are commercially the most important group, containing the nautilus, cuttlefishes, squids and octopuses. Octopuses are bottom-dwelling species usually limited to the neritic province. The genus *Octopus* consists of more than 100 species, and occurs in all marine habitats of the world. *Octopus vulgaris* is the most important and widely distributed species occurring throughout the tropical and temperate waters of the world[1]. In India, cephalopods started gaining importance with the development of an export market and consequent increase in demand. The annual production of cephalopods was 1,04,354 tonnes, valued[2] at more than Rs 800 crores during 2002–03. The body of the *Octopus* is utilized for food, while the tentacles and ink sac are used for biomedical research. Due to heavy demand, various species of *Octopus* were successfully cultured in pilot scale circulating seawater systems for biomedical research[3]. In India, *Octopus aegina* (Figure 1 *a*) is caught throughout the year by fishermen, but no information is available with regard to embryonic and larval development of this species.

Life histories of majority of octopuses are still unknown and our knowledge on octopus lifecycle is fragmentary. Some species like *O. cyanea*[4] and *O. vulgaris*[5] were studied under laboratory conditions. Octopus is a dioecious animal and fertilization is internal. The incirrate octopus lays eggs without gelatinous envelope around the egg chorion. In the benthic octopus, a feature that varies between species is the way in which the chorion stalks are glued to a substratum either individually or in small clusters with a common fixation disk or as festoons made from many interwoven stalks that are glued together[6]. Most females spawn only once. Females remain with eggs to brood and groom them throughout the development period, after which the females dies[7].

The samples were collected from Mandapam region, Palk Bay (lat. 9°45′N; long. 79°13′E) southeast coast of India. Live *O. aegina* caught in trawl nets were collected, transported and maintained in the laboratory. Feeding of octopus was done with small-sized live crabs @ 2–3 crabs per day per animal. When females laid the eggs, a portion of the egg cluster was removed from the brooding female and kept in a separate tank for observing the development. From this egg cluster, 5–10 eggs were taken out daily for noting the development stages using a stereozoom microscope with attached photographic facility. Samples of the eggs at various developmental stages were preserved in glycerine and alcohol (1/1 volume) for further observa-

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