

young baobab plants would not survive under such grazing pressure. In the arid climate of Mannar, many plants in the underbrush have evolved spines and thorns to protect themselves from the browsers and grazers. It is probable that these plants may also act as protective nurseries for the baobabs. Therefore, indiscriminate clearing of the scrub may expose the seedlings to grazing pressure from cattle.

There are no conservation areas in Mannar set aside especially for the protection of the baobab. That the baobab still survives in Mannar is due to its status as a 'zero-cost species' which does not compete with native species, and that the areas where it occurs today are inhabited by some of the most impoverished people who make little use of it: only their goats are fed on baobab leaves. In ancient times, the Arab traders who brought camels to Mannar fed the animals on the leaves of the baobab. A potential threat for the future may come from a rapid rise in the human population (through resettlement of refugees), the spread of settled agriculture, and the development of ill-considered and over-ambitious tourism facilities. The baobab has become a conspicuous component of the coastal biological diversity of Mannar and its ability to adapt to the harsh conditions prevalent in the island is in itself a justification for its conservation.

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Residue burning in rice–wheat cropping system: Causes and implications

Prabhat K. Gupta^{1,*}, Shivraj Sahai¹, Nahar Singh¹, C. K. Dixit¹, D. P. Singh¹, C. Sharma¹, M. K. Tiwari¹, Raj K. Gupta² and S. C. Garg¹

¹National Physical Laboratory, Dr. K.S. Krishnan Road, New Delhi 110 012, India

²CIMMYT India/RWC, ASC Complex, Pusa Campus, New Delhi 110 012, India

Combine harvesting technologies, which have become common in RWS (rice–wheat system) in India, leave behind large quantities of straw in the field for open burning of residue. Such burnings result in perturbations to the regional atmospheric chemistry due to emissions of trace species like CO₂, CO, CH₄, N₂O, NO_x, NMHCs and aerosols. The emissions of CH₄, CO, N₂O and NO_x have been estimated to be about 110, 2306, 2 and 84 Gg respectively, from rice and wheat straw burning in India in the year 2000. Residue burning causes nutrient and resource loss and adversely affects soil properties, thus calling for improvement in harvesting technologies and sustainable management of RWS.

RICE (*Oriza sativa*)–wheat (*Triticum aestivum*) cropping system has a long history in Asia. This cropping system has been practised¹ in Asia (China) since AD 700. In the Indian subcontinent, states like Uttar Pradesh (UP; India) have practised¹ this cropping system since 1872, and Punjab (Pakistan and India) and Bengal (India and Bangladesh) since 1920. Rice and wheat are currently grown in rotation on almost 26 million hectares (m ha) in South and East Asia¹. Rice–wheat system (RWS) occupies nearly one-fifth of the total area under these crops^{2,3}. The RWS is one of the widely practised cropping systems in India and covers about 9.5 m ha, about 90% of this area is concentrated in the Indo-Gangetic Plains (IGP)⁴. 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 food⁴. 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 RWS³.

Widespread adoption of Green Revolution technologies resulted in expansion in area under RWS, and subsequent

*For correspondence. (e-mail: prabhat@mail.nplindia.ernet.in)

inception of high-yielding varieties increased both crop as well as straw yield. In the past few decades, various advanced technological implements have been successfully introduced in agriculture. One such input is the use of combine harvester, particularly in the RWS. The major constraint in the RWS is the available short time between rice harvesting and plantation of wheat, and any delay in planting adversely affects the wheat crop. Preparation of the field also involved removal or utilization of rice straw left in the field. This led to the introduction of mechanized harvesting technologies to enhance efficiency and save time. Among the various harvesters introduced, combine mechanized harvesters have of late become the most popular in RWS. However, combine harvester leaves behind a large amount of loose straw in the field, whose disposal or utilization in the short time is again difficult, compelling farmers to burn the residue to get rid of it⁵. Northwestern part of the IGP has about 75% of the cropped area under combine harvesting⁵, which is about 15 m ha. As part of inventORIZATION of emission from open crop residue burning, it was estimated during this work that in the 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. These figures may rise sharply with increase in number of combines. In Punjab, only 25–30% of paddy was mechanically harvested⁶ earlier; however, use of combines has become more common now as its number in India has increased⁷ from nearly 2000 in 1986 to 3000 in 1991 and about 5000 in 1996. Burning of crop residue results in emission of trace gases and particulate matters, loss of plant nutrients and thus adversely affect the pedology. It has been estimated that for the year 2000 the emission of CH₄, CO, N₂O and NO_x was 110, 2306, 2 and 84 Gg respectively, from the field-burning of rice and wheat straw in India.

In 2000, the total agricultural residue production in India was 347 million tons, of which rice and wheat straw accounted for more than 200 million tons⁸. For every 4 tons of rice or wheat grain, about 6 tons of straw is produced⁸. Large amount of crop residue is produced from RWS in India from major involved States, viz. UP, MP, Punjab, Bihar, Maharashtra, Haryana, Gujarat and HP. According

to this detailed state-wise study for the year 1994, the amount of residue generated from rice and wheat from the above-mentioned States is 133 Tg (Tg = million tons), which includes the highest from UP (13 and 33 Tg) followed by Punjab (10 and 20 Tg) and MP (8 and 11 Tg) respectively, (Table 1).

According to Sarkar *et al.*⁹, the RWS accounts for nearly one-fourth of the crop residue production in India. The residue generated is 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. However, in case of combine harvesting almost all the residue generated is left in the field, that finally ends up in burning.

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 (Figure 1). Due to the use of combine harvesters, there has been a sharp increase in the share of residue that is left in the field as it leaves major portion of the residue, including husk in the field. About 5–7 tons/ha of rice straw is left unused in the field⁵. Collection and disposal of the residue remain a practical problem and all options lack economical feasibility. Increasing labour wages and labour shortage prevent timely manual harvest in major rice-wheat growing areas of India.

Self-propelled and tractor-mounted combinations are being used (for harvesting); though these incur high capital costs, they remain economical when compared to other options available⁸. The main options left are *in situ* incorporation and burning in the field. *In situ* incorporation is not feasible as the decomposition of residue takes a long time and affects the growth of wheat crop. Thus, for a farmer it is economical and easier to burn the residue in the field to enable early sowing. 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, as discussed below.

Table 1. Rice and wheat crop production and residue generation from major states in 1994 (Gg)

States – 1994	Rice		Wheat		Total	
	Production	Residue	Production	Residue	Production	Residue
UP	10326	13284	22126	33189	32452	46473
Punjab	7688	9890	13501	20251	21189	30141
MP	6308	8115	7151	10727	13459	18842
Bihar	6251	8041	4296	6443	10547	14484
Haryana	2185	2810	7285	10928	9470	13738
Maharashtra	2419	3112	1097	1646	3516	4758
Gujarat	916	1179	1704	2555	2620	3734
HP	110	141	553	829	663	970
All India	81435	88474	64285	96428	145720	184902

Burning of agricultural residue is now recognized as an important source of pollutant emissions (Figure 2). It leads to emission of trace gases like CH₄, CO, N₂O, NO_x, SO₂, and hydrocarbons. It may also lead to adverse impacts on health of the population in the region. 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 burning⁶ releases 3 kg particulate matter, 60 kg CO, 1460 kg CO₂, 199 kg ash and 2 kg SO₂. 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. Following the IPCC methodology¹⁰ for estimation of emission from open burning of crop residue and assuming that one-fourth¹⁰ of the available residue is burnt in the field, it is estimated that the emissions of CH₄, CO, N₂O and NO_x were 102, 2138, 2.2 and 78 Gg respectively, in 1994 that rose to 110, 2306, 2.3 and 84 Gg respectively in 2000 from field-burning of rice and wheat straw in India (Table 2). According to Ministry of Environment and Forests¹¹ in the year 1994, India's net national emission of CH₄ and N₂O from all the sources was 18083 Gg and 178 Gg.



Figure 1. Combine harvester in operation.



Figure 2. Open burning of straw in wheat field after combine harvesting.

Both rice and wheat are exhaustive feeders, and the double cropping system is heavily depleting the soil of its nutrient content. A rice–wheat sequence that yields 7 tons/ha of rice and 4 tons/ha of wheat removes more than 300 kg N, 30 kg P and 300 kg K/ha from the soil¹². Though little is known about the effect of burning on nutrient loss and dynamics in the RWS, it has been reported that 40–80% of the wheat crop residue N is lost as ammonia when it is burnt in the field¹³. In the United Kingdom, it has been observed¹³ that the emission of ammonia declined from 20 Gg N per year in 1981 to 3.3 Gg N per year in 1991, as a result of changes in agricultural practices because of an imposed ban on the burning of crop residue. According to Samara *et al.*¹³ in New Zealand, for every ton of wheat residue burnt, 2.4 kg of N was lost. Likewise, sulphur (S) losses from the burning of high S and low S rice-crop residues in Australia were 60 and 40% of its content respectively¹⁴. This burning may lead to considerable nutrient loss also. Crop residues are a good source of plant nutrients and are important components for the stability of the agricultural ecosystem. About 25% of N and P, 50% of S and 75% of K uptake by cereal crops are retained in crop residues, making them viable nutrient sources¹².

Pedology is the basis for agricultural and rural sustainability. The heat from burning cereal straw can penetrate into the soil up to 1 cm, elevating the temperature as high as 33.8–42.2°C. About 32–76% of the straw weight and 27–73% N are lost in burning² (Figure 3). Bacterial and fungal populations are decreased immediately and substantially only in the top 2.5 cm of the soil upon burning. Repeated burning in the field permanently diminishes the bacterial

Table 2. Comparison of all-India emissions from rice and wheat residue open burning in 1994 and 2000 (Gg)

Year	CH ₄	CO	N ₂ O	NO _x
1994	102	2138	2.2	78
2000	110	2305	2.3	84

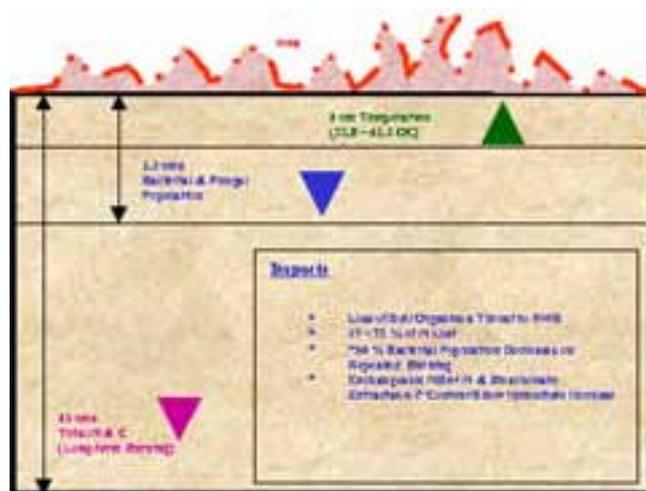


Figure 3. Impact of residue burning on the soil.

population by more than 50%, but fungi appeared to recover and also decreased soil respiration. Burning immediately increased the exchangeable $\text{NH}_4^+\text{-N}$ and bicarbonate extractable-phosphorus content, but there was no build-up of nutrients in the profile². Long-term burning reduces total N and C and potentially mineralized N in the 0–15 cm soil layer¹⁵. One of the recognized threats to the RWS sustainability is the loss of soil organic matter as a result of burning⁵.

The straw collected from the fields is of great economic value as livestock feed, fuel and industrial raw material. In northern India, wheat straw is preferred while in South India rice straw is fed to livestock⁸. The residue generated from the RWS can be put to many uses as discussed earlier, but this is possible if the residue is separated from the grain and carried out of the field. Burning reduces the availability of straw to livestock, which is already in short supply⁸ by more than 40%. However, in case of combine harvesting most of the residue is left in the field for burning adversely affecting overall sustainability of the RWS.

The options for crop residue management may include developing systems to plant into residue, baling and removal for use as animal feed or for industry. Enhanced decomposition of machine-harvested straw to improve nutrients in the soil can be useful. The use of microbial sprays that can speed decomposition of residue is also an option. The option of planting into residue needs further investigation. According to Singh¹², incorporation of cereal crop residues immediately before sowing/transplanting into wheat or rice significantly lowers crop yield because of immobilization of inorganic N and its adverse effect due to N deficiency. However, in few studies, wheat yields were lower during the first one to three years of rice straw incorporation 30 days prior to wheat planting, but in later years, straw incorporation did not affect wheat yields adversely¹². An experiment conducted at Modipuram, inferred that with conventional tillage and under different crop residue management practices, viz. removal of residue, burning of residue and incorporation of residue, the grain yields recorded were 5.37, 5.54 and 5.81 tons/ha respectively¹⁶. Presently, only a few farmers have opted to incorporate rice residue into the soil before wheat. The raised-bed planting system offers avenues for incorporating residue by attaching shovel-type openers in front of the seed-cum-fertilizer openers and bed-shaper. The shovel shapes the old beds and covers the crop residues with soil taken from the furrows.

Conservation of rice straw as livestock feed and/or its utilization as industrial raw material requires a series of on-farm and off-farm operations, including collection, packaging, handling, transportation, storage and pre-feeding processing⁸. These operations are important steps of residue management and should involve least input and maximum sustainable residue utilization. For collection of straw after combining, imported conventional field balers are available. These balers, however, recover only about 25–30% of potential straw yield after combining, depending upon height of plant cut by combines⁸. Baling cost is Rs 800

per ha⁸. The total cost of operation, including baling, collection, transportation up to 5 km distance, and stacking is Rs 1300 per ha or Rs 650 per ton of straw⁸. In the Patiala district, Punjab, a 10 MW_e power plant is under installation to use paddy straw as the sole fuel⁶ which is an important example of sustainable residue utilization.

To facilitate the drilling operation in combine harvested fields, the first step should be to attach flappers or swappers to combines for shredding of rice residue and to spread them more uniformly. Leaving mulch on the surface improves soil moisture and thermal regimes, and improves the early vigour of wheat seedlings and subsequently system productivity⁵. Another way is to modify the zero till–drill machines available in the region by increasing tine lengths and spacing between tines for greater clearance of residues. Replacement of point-openers with pre-opener discs together with double disc openers or the use of star-wheel-type seed placement devices as used in Zimbabwe, can establish crop into loose residues without tillage⁵. Finally, the following should be targeted for the future:

- *In situ* incorporation being the best option, may be further investigated for fast decomposition of residue.
- Technological improvements in the implements used, so that the option of planting into residue, drilling operation, *in situ* incorporation, etc. can be made feasible.
- Modification of combine harvesters, whereby the residue also is separately collected and removed from the field.
- More reliable data, on the effect of RWS management (including residue quality, application rate, application method, timing, interactions with inorganic fertilizers, temperature, soil moisture, soil type and tillage) on decomposition and nutrient release rates and the production of phytotoxic compounds for rice and wheat residues, are needed.
- Proper researcher–farmer interface needs to be established.
- Realistic process-based computer simulation models may be developed for RWS to accommodate the variables and complexities of interactions among soil, crop and climate, and for accurate prediction of the effect of crop residue management practices on nutrient cycling, crop growth and yield, and soil properties. Moreover, Geographical Information System should be used for natural resource management.
- Long-term experiments at sites carefully selected for variation in temperature, moisture regimes, soil mineralogy and agriculture management covering the RWS may be established.
- Customs duty on implements like balers should be exempted to reduce the cost involved in residue management.
- Operation of field balers over large areas (400 ha annually) should be facilitated to break even with existing harvest price and price of straw to enable RWS sustainability.

- Government should monitor and discourage burning of crop residue through incentives and technology transfer and utilization.

Residue burning in the RWS 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. The gaseous emissions have been estimated to be 110, 2306, 2 and 84 Gg respectively, for CH₄, CO, N₂O and NO_x from rice and wheat straw burning in India in 2000, which is a noticeable increase in comparison to 1994. There is need to review and upgrade the technology involved with mechanized harvesters, for sustainable utilization of residue thereby overcoming the compulsion to burn residue in the rice-wheat cropping system, the major concern being the short time between harvesting of rice and planting of wheat. Long-term studies on residue incorporation, investigation on resource depletion and related environmental and rural sustainability are required.

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Characterization and expression of *AmphiCB* encoding a cathepsin B proteinase from amphioxus *Branchiostoma belcheri tsingtauense*

Yongjun Wang^{1,2}, Shicui Zhang^{1*}, Zhenhui Liu¹, Hongyan Li¹ and Lei Wang¹

¹Department of Marine Biology, Ocean University of China, Qingdao 266003

²Department of Fishery, Nantong Agricultural College, Nantong 226007

In this study, an amphioxus cDNA, *AmphiCB*, encoding cathepsin B proteinase was isolated from the gut cDNA library of *Branchiostoma belcheri tsingtauense*. It has an open reading frame encoding a precursor protein which consists of 333 residues, including a signal peptide, a pro-peptide and a mature proteinase. The mature *AmphiCB* has all conserved structures characteristic of cathepsin B. The phylogenetic tree constructed shows that *AmphiCB* appears more closely related to invertebrate cathepsin B. Northern blotting and RT-PCR demonstrate that *AmphiCB* transcript was present in all tissues examined, with much stronger expression in the hind-gut and hepatic caecum. This suggests that *AmphiCB* is possibly actively involved in food digestion, in addition to its housekeeping role.

CATHEPSINS are lysosomal cysteine proteinases belonging to the papain superfamily (C1A), which have been classified

*For correspondence. (e-mail: sczhang@ouc.edu.cn)