Tackling Air Pollution from Agricultural Residue Burning: The Aakash Project: Challenge for Reduction of Rice-Stubble Burning in the Indian Punjab Region

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Abstract

The Delhi metropolitan area experiences severe air pollution every year in late October or early November. Corresponding to this period, post-harvest rice stubble burning is widely practiced in the surrounding states of Punjab (India) and Haryana, and in some parts of Uttar Pradesh and Himachal Pradesh. The Research Institute for Humanity and Nature's (RIHN's) Aakash Project, a cooperative project between Japan and India, has been tackling the issue of air pollution from large-scale rice stubble burning in the Indian Punjab region. The project was launched as an RIHN full research project in April 2020 and will continue until March 2025. This project scientifically examines the connection between stubble burning in the Punjab and severe air pollution in Delhi. Based on this scientific understanding, we will pursue a pathway of social transformation toward clean air, public health and sustainable agriculture. We are approaching stakeholders/involved parties to raise awareness regarding farmer/community behavior that is relevant to stubble burning and air pollution. So far, under the project, we have successfully conducted campaign-based measurements using about 30 small air-pollution measurement devices in the field in 2022 and clarified the linkage between stubble burning in the Punjab and severe air pollution in Delhi. To clarify the goals of our activities, this paper focuses on the underlying issues at stake, describes the current research and findings, and discusses possible mitigation measures. At the end of the project, we aim to make recommendations for creating a sustainable agricultural system that reduces rice-stubble burning.

Key words: Aakash Project, agriculture system, air pollution, Green Revolution, India, stubble burning

1. Introduction: Serious Air Pollution in India

India is considered to have one of the highest numbers of deaths from air pollution. According to the World Health Organization (2023), India had about 883 thousand fatalities attributable to air pollution, second only to China in terms of numbers. There are many industrial sources of air pollution: the energy, industry, transport, waste and other sectors (Guttikunda *et al*., 2023). In many countries where agriculture is a major industry, agricultural waste burning can be a significant source of air pollution. In the Indo-Gangetic Plains (IGP) of India, a double cropping system has taken root, with "Kharif" crops (mostly rice) during the monsoon season and "Rabi" crops (mostly wheat) during the winter. The burning of crop residues from these crops often causes severe air pollution in the surrounding areas.

Since the 2010s, serious air pollution episodes have repeatedly occurred in the National Capital Territory of Delhi (Delhi-NCT) in October and November. Schools have often been closed and many events have been cancelled due to serious air pollution, and the impact on the lives of citizens has become increasingly severe. Post-harvest rice-stubble burning is widely practiced in the surrounding states of Punjab (India) and Haryana, and in some parts of Uttar Pradesh and Himachal Pradesh from late September to the end of November, corresponding to the period of serious air pollution in Delhi-NCT (Sidhu *et al*., 1998; Samra *et al*., 2003; Gupta *et al*., 2004; Vadrevu *et al*., 2011; Irwin, 2014). Here, stubble refers to the short stalks and straws left on the field after the harvest of wheat or rice. The term "stubble burning" is used in this paper to indicate the burning of stubble left on the ground together with scattered pieces of the stalk and straw (Fig. 1). Recently, rice-stubble burning has become more active and is suspected to be related to the increasingly severe air pollution in Delhi-NCT (Cusworth *et al*., 2018; Liu *et al*., 2018; Balwinder-Singh *et al*., 2019; Beig *et al*., 2020). However, the link between stubble burning in the surrounding states and Delhi's air pollution has not been well-established scientifically and is often controversial. Previous studies have found it difficult to quantitatively assess the extent to which rice stubble burning has impacted air pollution in Delhi because satellite observations of stubble burning (i.e., fires or hotspots) are often obstructed by clouds or dense fog from stubble burning, so the air pollutant emissions from stubble burning are difficult to quantify. More significantly, on the ground, most air pollutant monitoring stations are located in urban areas and no data are available for rural areas, making quantitative analysis of air pollution in rural areas very difficult.

On the other hand, recent satellite observations have revealed that dense smog is spreading across the Indian Punjab (Vadrevu *et al*., 2011) and further eastern part of the IGP (Kaskaoutis *et al*., 2014; Sarkar *et al*., 2018a; 2018b). The IGP is a densely populated area where human activities have caused severe air pollution, and there are indications that this air pollution is having a negative impact on premature mortality (Ghude *et al*., 2016). If air pollutants from stubble burning are added to this, the situation is likely to worsen.

The Aakash Project was launched as a research project at the Research Institute for Humanity and Nature (RIHN) in April 2020 to tackle the issue of air pollution from large-scale rice-stubble burning in this region. It is a collaborative project between Japan and India, with about 30–40 researchers in each country (https://www.chikyu.ac.jp/rihn_e/activities/project/project/10/). This project utilizes observation data and model simulations to examine scientifically the connection between stubble burning in the Punjab and severe air pollution in Delhi. Based on this scientific understanding and considering the region's cultural and socio-economic background and the people's awareness of the negative impacts of air pollution on their health, we will pursue a pathway of social transformation toward clean air, public health and sustainable agriculture.

During the first three years of the project, human exchange between India and Japan was almost completely closed due to the COVID-19 pandemic, but various activities were carried out with the full cooperation of the members on the Indian side. From September to November 2022, we deployed about 30 small air pollution measurement devices in an area from Punjab through Haryana to Delhi-NCT and succeeded in clearly demonstrating the linkage between air-pollutant emissions due to rice-stubble burning in the Punjab and severe air pollution in Delhi-NCT (Singh *et al*., 2023). In parallel with these field measurements, we explored the root

Fig. 1 Representational image of rice stubble burning in Punjab (taken by the author on 4 November 2018).

causes of this problem through questionnaires, interviews with local farmers and a literature review. It is well known that the over-intensive wheat/rice double cropping system in the Punjab region, situated in a semi-arid zone where rice is not the staple food, has caused various environmental problems such as groundwater depletion (Tiwari *et al*., 2009) and soil degradation (e.g., Grace *et al*., 2003; Samra *et al*., 2003). The Green Revolution in the Punjab can be considered a success, in part, because it transformed the food-poor Indian economy into a self-sufficient one. However, that success was achieved at great environmental and social cost (Ramakrishnan, 2008). In recent years, there has been noticeable criticism of the success of the Green Revolution with regard to groundwater depletion and soil degradation (e.g., Glaeser, 1987). However, the burden on the environment now extends not only to natural resources such as water and soil, but also to the clean air that is essential to our lives. This issue is an example of how the changing agricultural system can threaten clean air, which is an essential aspect of public health and human well-being.

Under this project, several mitigation options for reducing stubble burning are being tested in the field as possible solutions to this problem. At the end of this project, its findings will be disseminated to government agencies, communities and local residents to provide recommendations for new policies and changes in behavior. This paper introduces the Aakash Project initiative and describes the air pollution problem caused by rice-stubble burning, focusing on the case of Punjab, India. First, the circumstances of the problem are described, and the root causes of the need for stubble burning are discussed in Section 2. Then, the linkage between stubble burning in Punjab and air pollution in Delhi is described in Section 3, and possible solutions to this problem are examined in Section 4. Finally, the future prospects are described in Section 5.

2. Contextual Background of the Problem

2.1 Green Revolution and Establishment of a Wheat-Rice Double Cropping System

The word Punjab is derived from the Persian word *panj ab*, meaning “five waters.” Originally, the Punjab region referred to the basin of the Indus River and its four tributaries. Under its current administrative divisions, it corresponds to the state of Punjab in Pakistan and the states of Punjab, Haryana and Himachal Pradesh on the Indian side. The Punjab region is situated in a semi-arid zone, and parts of the region receive little precipitation, with an annual rainfall of less than 500 mm. Although some areas in the central part of the Punjab have long been suitable for agriculture, until the 19th century, the rest of the region was semi-arid and arid land unsuitable for farming (D.M. Singh, 2018). Traditional agriculture originally consisted of mixed farming, that is, a combination of cultivating wheat and raising livestock (cattle and buffalo). The British, after colonizing the Punjab, expanded the irrigation network of canals and turned parts of the region into a vast agricultural area, primarily in the regions of the Indus River and its tributaries. Sugimoto and Usami (2014) analyzed the historical conditions that made possible the “successful Green Revolution” in the Indian Punjab region: After the 1947 secession, the Punjab region under British rule was divided into the western (Pakistan) and eastern (India) partitions. Many Sikhs and Hindus who had been engaged in agriculture in the western canal colonies migrated to India, bringing with them knowledge of the latest agricultural technology of the time. Furthermore, since the irrigated farmland in the western Punjab was incorporated into Pakistan, the Indian government aggressively developed canal irrigation. Most of the irrigation projects promoted by the Indian government were either improvements to facilities completed during British rule or realizations of projects that had already been planned, but the Indus River basin was also rich in groundwater from the glaciers of the Himalayas. Since the 1950s, these powerful canal irrigation projects and the widespread use of tube wells have greatly increased the region’s irrigation capacity. As a result, the irrigated area in the Punjab region has increased significantly, leading to increased agricultural production.

Starting in the 1960s, with the commencement of the so-called “Green Revolution,” agriculture took on a central role in supporting food production for the populous nation of India. In the late 1960s, new agricultural technologies were introduced, with high-yielding varieties (HYVs) of wheat after the mid-1960s and rice in the early 1970s, accompanied by expansions of irrigation infrastructure and the massive application of fertilizers and chemicals. As a result, rice and wheat productivity in the Punjab increased dramatically (Vatta and Budhiraja, 2021). Details of the changes in land use in the Punjab between 1960 and 2016 are shown in Table 8.1 of Vatta and Budhiraja (2021). In 2016, most of the cultivated land was irrigated and the rate of HYV adoption reached 100%. Fertilizer inputs were 38 times higher in 2014–2015 than in 1965–1966. From the early 1960s to 1990, the rice hectarage increased from 250,000 ha to 2 million ha. During the same period, the wheat hectarage increased from 1.5 million ha to 3.2 million ha. By 2000, more than 80% of the total cultivated land was under rice and wheat. On the other hand, the area under traditional crops— such as maize, beans, oilseeds, sugarcane and cotton— has shrunk, and thus the crop diversification index has declined rapidly (Singh *et al*., 2011; Vatta and Budhiraja, 2021). The introduction of mechanical agricultural technology, such as tractors and combine harvesters, mitigated the demand for labor during the busiest season between harvesting and sowing the next crop, which was another factor that contributed to establishing the wheat–rice cycle in the region.

Here, the impact of government policies should also be mentioned. In 1965, the Indian government established the Commission for Agricultural Costs and Prices (CACP) and the Food Cooperation of India (FCI). These two organizations played critical roles in determining the prices of wheat and rice in India. The CACP recommended a Minimum Support Price (MSP) and FCI procured rice and wheat from farmers at the MSP. The FCI's purchases of rice and wheat from northwestern India, including the Punjab, were prioritized over those from other regions (Sugimoto and Usami, 2014). Thanks to this policy, Punjabi farmers were able to profit from rice and wheat production without the risk of a price collapse. Thus, the practice of double cropping of rice and wheat took root, and Punjab's grain production steadily increased. In 2014–2015, Punjab produced 24.2 percent of the nation's rice and 41.5 percent of the nation's wheat and contributed 8.63 million tons of rice and 10.21 million tons of wheat to the national food grain pool in 2010–2011 (Vatta and Budhiraja, 2021). Punjab was considered a successful example of the Green Revolution and came to be known as the "breadbasket" of India.

However, overly intensive agricultural practices were beginning to cause irreversible environmental damage. In particular, it is widely known that the expansion of cultivated land and the increased number of tube wells have lowered the groundwater table in the Punjab region. Rice production requires much more water than wheat production. Since canal irrigation alone was not enough to water the expanding farmland, farmers began to install tube wells on their own. The development of tube wells was also related to the government's electricity policy. The introduction of tube wells was supported by government policies of rural electrification and subsidies for agricultural electricity (Sato, 2021), which were then followed by the provision of free electricity from 1997 (Sarkar and Das, 2014). Expansion of tube well irrigation was an important factor in the establishment of the current rice–wheat double-cropping system in Punjab (Vatta and Budhiraja, 2021; Sato, 2021). As a result, the groundwater level has been declining year by year, despite various discussions and recommendations on groundwater conservation (e.g., Kumar *et al*., 2005).

Furthermore, the bias toward the double cropping of rice and wheat has resulted in the loss of certain soil nutrients. There is also a link between the declining groundwater table and soil degradation. Percolated groundwater is high in salinity and prone to causing salt damage to crops. In addition, the lowering of the groundwater table causes physical compaction of the soil, further degrading it. Thus, intensive agriculture with a heavy bias toward rice and wheat has been causing serious soil degradation. Because of this, it has been noted as early as the 1970s that yields have reached a ceiling and not increased, despite massive fertilizer inputs (Grace *et al*., 2003; Samra *et al*., 2003).

On the other hand, a survey by Singh *et al*., (2011) clarified that many farmers were adhering to the wheat and rice system for the time being. Given the current market system and the state of farming technology, this practice appeared to be the most reliable to them in the short term. The lack of marketing infrastructure for crops other than wheat and rice may also help explain the preference for the wheat–rice cropping pattern and the

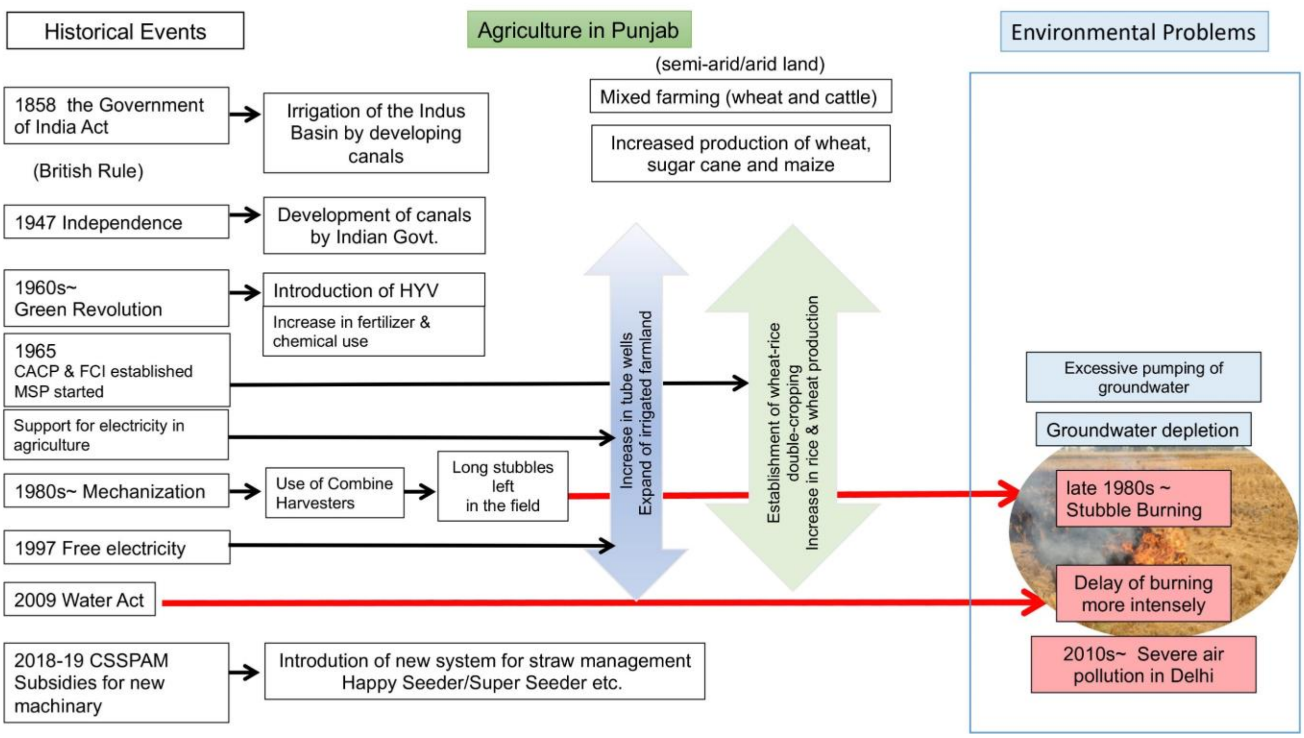

Fig. 2 Circumstances of the stubble burning problem.

reluctance to try new cropping systems.

Despite the success of the Green Revolution in the Punjab in terms of improved productivity, it has been the subject of severe criticism for ecological reasons since the 1970s. The most prominent criticisms are the excessive use of groundwater, the soil degradation, the creation of a monoculture with a bias toward rice and wheat, and the excessive use of chemical pesticides; but in the 2000s, air pollution from the increasingly common practice of mass burning of rice stubble rapidly gained attention. A schematic diagram of background factors in rice-stubble burning is given in Fig. 2.

2.2 Causes of Rice-Stubble Burning

Prior to the introduction of agricultural machinery in the 1980s, rice and wheat straw were manually cut close to the ground during harvest. With combine harvesters, conversely, the blades must be set high enough to prevent them from hitting the ground, leaving long stubble with scattered straw in the field. To get rid of this stubble, burning was reported to have begun in the late 1980s. Based on interviews with farmers in Punjab state, Gupta (2011; 2012) revealed that the most important factor determining whether rice-stubble burning was practiced was the use of combine harvesters. She noted that coarse rice producers were considerably more likely than basmati-rice producers to use combine harvesters. Basmati rice has a higher commercial value, and farmers tend to avoid using combine harvesters for fear of damaging the grain. Today, harvesting, including of basmati rice, appears to be done almost exclusively with combine harvesters, yet our research indicates that stubble burning is more common in coarse rice-growing areas than in basmati rice-growing areas. (Asada and Vatta, 2021).

Meanwhile, groundwater levels have continued to fall unabated. In 2009, the Punjab state government, together with the Haryana state government, implemented the Preservation of Subsoil Water Act, which prohibited the transplanting of rice seedlings before the start of the monsoon season to conserve groundwater, thus delaying the start of rice planting. Promulgation of the Water Act induced important changes in the timing and manner of rice-stubble burning. In the wheat-rice double-cropping system, the wheat harvest must take place before the May heat wave arrives, so farmers must finish sowing wheat by late November. After the Water Act in 2009, rice transplanting was delayed, and, thus, so was harvesting. As a result, the period for dealing with rice stubble was shortened, and rice stubble has since been burned more intensively. Satellite-borne Moderate Resolution Imaging Spectroradiometer (MODIS) sensor observations of fires have significantly contributed to understanding the delay in the burning season (Sawlani *et al*., 2018; Jethva *et al*., 2018; Sembhi *et al*., 2020; Kant *et al*., 2022). Now, it is well known that large quantities of rice stubble are intensively burned during the short period in late October and early November. This period corresponds to a time of meteorological change; the winds become northwesterlies, which carry the pollutants directly toward the Delhi-NCT under low-temperature, stagnant conditions. It is assumed that this is closely related to the increasing severity of air pollution in the Delhi-NCT since the 2010s, especially in early November. To clarify the linkage between stubble burning and severe air pollution in Delhi, the Aakash Project aimed to conduct local air pollutant measurements during this period, taking into account meteorological conditions and the movement of air masses.

3. Linkage between Stubble Burning in the Punjab and Air Pollution in Delhi

Generally, burning biomass like rice stubble releases various atmospheric pollutants due to incomplete combustion of organic matter. Secondary particulate matter known as “$PM_{2.5}$” is produced from precursors such as volatile organic carbon (VOC), nitrogen oxides (NOx), and sulfur oxides (SOx). As clarified by a well-known study of six cities in the U.S., $PM_{2.5}$ poses a prominent risk to human health (Dockery *et al*., 1993). Therefore, $PM_{2.5}$ is the most widely used indicator of the health hazards posed by air pollution. According to the WHO guideline updated in 2021, annual average concentrations of $PM_{2.5}$ should not exceed 5 μg/m^3, while 24-hour average exposures should not exceed 15 μg/m^3 for more than three to four days per year. The daily observed values in Delhi from late October to early November, however, have often indicated levels in excess of several-hundreds μg/m^3 and sometimes even 1,000 μg/m^3.

The cause-and-effect relationship between stubble burning in the Punjab region and worsening air pollution in Delhi has not yet been established quantitatively. Though some previous studies (Cusworth *et al*., 2018; Beig *et al*., 2020) have conducted simulation-based studies, it is difficult to quantitatively assess the extent to which rice-stubble burning has impacted air pollution in Delhi, because of the lack of air pollution monitoring networks in rural areas. Most monitoring stations for air pollutants are located in urban areas, with no data available for rural areas.

In 2022, the Aakash Project conducted intensive campaign-based air pollutant measurements during the stubble burning season to establish the link between stubble burning in the Punjab and air pollution in Delhi. The target area was divided into 30 grids (~60 × 40 km). A network of 32 compact $PM_{2.5}$ and gas sensors (CUPI-Gs) and seven sensors specific to $PM_{2.5}$ (P-sensors) were established in rural and semi-rural areas of Punjab, Haryana and western Uttar Pradesh. Some sensors were also installed in the cities of Gurgaon and inside Delhi to obtain data to compare with the data from the source areas. The sensors were developed by project members Y. Matsumi and T. Nakayama, with the cooperation of Panasonic Inc. (see Nakayama *et al.*, 2018 for details on the $PM_{2.5}$ sensor). The installation sites were selected based on the prevailing northwest winds from the Punjab to Delhi-NCT, because (as mentioned in 2.2) the seasonal winds change direction in early November and transport air pollutants from the Punjab to Delhi city. Near real-time measurements were taken from September 1 to November 30, 2022. The uniqueness of our method lies in the fact that many of the sensors were densely located in rural areas rather than urban areas. Our measurements revealed that all target areas were covered by polluted air masses, which demonstrated that Delhi's air pollution was not just a Delhi problem. The entire northwestern region of India was covered by a single smog dome (Singh *et al.*, 2023).

Local residents in the agricultural areas are also being exposed to health problems due to the severe air pollution. Until now, the urban-centered monitoring of air pollution has left the people in rural areas unaware of the risks. In parallel with the air quality measurements, we conducted a questionnaire survey of farmers living in the Punjab in 2020, which revealed that they had little awareness of the consequences their stubble burning was having on Delhi-NCT. By publishing the results of the measurements, we hope to bring about a change in the behavior of all parties involved, recognizing not only the impact on Delhi, but also the fact that it is the rural people who are exposed to the greatest health risks.

4. Mitigation Options for the Stubble-burning Problem

4.1 Increasing Crop Diversification

In Section 2, I described how the cultivation system in the Punjab region became biased toward double cropping of rice and wheat. The cultivation of traditional products (e.g., pulses, maize, oilseeds, cotton, sugarcane) declined after the Green Revolution (Singh *et al.*, 2011; Vatta and Budhiraja, 2021), and reversing this trend, thus reducing reliance on the rice–wheat system and increasing crop diversification, was an attractive mitigation option. To ensure long-term sustainability, the Indian government needed to take corrective measures in the country's production system, which led to the establishment of three commissions: the Jowl Commission in 1986, the Jowl Commission in 2002, and the Alag Commission in 2005 (Vatta *et al.*, 2013). However, despite the recommendations of those committees to reduce rice and wheat acreage and switch to other crops, rice and wheat acreage increased. There are many reasons for the failure of crop diversification. The rice-wheat rotation was clearly economically advantageous, and other crops lagged far behind in terms of profitability (Vatta *et al.*, 2013). For farmers rice is a low-risk operation protected by the MSP, and there is no reason for them to convert to other crops. To promote crop diversification, it is important to secure markets and stabilize the prices of the alternatives.

In the Aakash Project, we are working with Lovely Professional University (LPU) in the state of Punjab to conduct growing experiments and identify viable crops of high economic value as an alternative to rice production. In parallel, we are seeking cooperation from Japanese companies to discuss crops that could be purchased. In addition, we are experimenting with the production of biochar from agricultural residues in LPU fields, with the aim of developing new agricultural technologies and markets aimed at carbon fixation.

4.2 Compensation

Farmers can use machinery to re-cut the long stubble after harvesting, and the straw scattered throughout the field can be used for purposes other than burning, but this requires hiring workers to collect and remove it from the field. Pant (2013) recruited farmers from the southern lowland Terai region in Nepal and invited them to submit "sealed bids" for compensation to refrain from burning for a season. He found that the median value of the bids was around 78 US dollars (USD) per hectare, i.e., farmers were willing to accept roughly this amount to stop burning (Pant, 2013; Irwin, 2014).

On November 7, 2019, the Supreme Court of India ordered the governments of Punjab, Haryana and Uttar Pradesh to pay a reward of 100 Indian Rupees (INR) per quintal, corresponding to about 3,000 INR per acre, within a week to farmers who stopped stubble burning in non-basmati rice cultivation. This was in response to severe air pollution in Delhi-NCT that had been reported one week previously (November 8th, *Tribune*). During this same period, significantly reduced visibility in the Punjab was also reported. Conversion based on the exchange rate at the time shows a reward amount of about 73 USD per hectare, comparable to the amount suggested by Pant (2013). When we visited the Cooperative Society of Latala Village in the Ludhiana district of Punjab in November 2019, farmers there indicated that most farmers would accept this amount of compensation to stop burning. On November 9, the Punjab state government, following a Supreme Court directive, initiated the reward payment process. However, because of many flaws in the system and the occurrence of fraudulent payments, it was soon suspended, and almost no compensation was ultimately paid.

4.3 Subsidies for Introduction of New Machinery (In-situ Straw Management)

Paying compensation every year to stop rice-stubble burning is not considered a sustainable measure (Irwin, 2014). The central government of India believes it would be more beneficial to introduce new types of agricultural machinery. In 2018–2019, the central government provided significant subsidies to support farmers who installed new agricultural machinery, such as the Happy-Seeder, Super-Seeder and others. This policy was called the Central Sector Scheme for Promotion of Agricultural Mechanization (CSSPAM). Punjab Agricultural University (PAU) issued a report, based on interviews with farmers, examining the effectiveness of the CSSPAM measures (Kumar *et al*., 2022). The government provided subsidies to Punjab to install 90,000 units of agricultural machinery and to educate farmers on the benefits of new technology for shallow incorporation of straw into soil, using new machines. However, despite these subsidies, stubble burning has not subsided, and by 2020 straw burning was taking place in 60% of all paddy fields in the Punjab. According to the PAU report, for farmers to accept this new method of cultivation more training will be needed. At this point, CSSPAM is certainly not a definitive solution to stubble burning, and the situation is not expected to change drastically in the next few years.

4.4 Ex-situ Management of Rice Straw

Ex-situ management involves taking rice straw out of the field and using it for other purposes. Potential uses for rice straw include cattle feed, paper-making material (Singh and Arya, 2021), mulch for other crops, bedding for garlic and mushrooms (Vatta and Budhiraja, 2021), packaging material (Ibrahim *et al*., 2021), fuel for baking bricks, and compost for fertilizer. In recent years, there has been a growing trend to develop new technologies for reusing rice straw as a resource (Singh and Arya, 2021). Some farmers are utilizing rice straw for mulching potato or horticultural crops, and its use as bedding for garlic and mushrooms is popular all over India.

In the Punjab, there is little demand for rice straw as fodder because of the abundance of wheat straw. Since wheat straw is preferred by cattle, many farmers use it as fodder instead of burning it, though some wheat straw is still burned. Only a small nomadic people called “Gujjars” uses rice straw as fodder, as it is about one-sixteenth the price of wheat straw. Though livestock feed is scarce in India as a whole, it is not easy to transport straw over long distances, and a domestic market in India is likely not a promising option.

On the other hand, expectations have been growing in recent years for the use of rice straw as a biofuel. In October 2021, the Ministry of Power (MoP) amended an existing policy on biomass usage. The ministry made it mandatory for coal-based thermal plants to use at least 5% biomass pellets made primarily of agro-residue in energy generation. This policy is called Mission SAMARTH (Sustainable Agrarian Mission on Use of Agro Residue in Thermal Power Plants). Co-firing with 5%–10% biofuel requires 76–152 mega-tons of pellets (Kamal Vatta, private communication, 2022). Such large demand for rice straw would likely have a significant social impact. Companies that collect rice straw and sell it to electric power companies have already emerged, and there are examples of Japanese companies supporting them. The Aakash Project is currently working with Japanese government officials and related companies to gather information (see materials from the India-Japan Environmental Week on January 12–13, 2023: https://aakash-rihn.org/en/indiajapan-environmentweek2023/), and in the future, we would like to promote cooperation between Japan and India for introduction of technologies that contribute to the effective use of rice straw.

5. Future Prospects

The Aakash Project will continue until March 2025, and the research results described in this review will only be part of the total. We plan to make additional observations at the site between September and November 2023, and simulation studies are ongoing. In addition, members of the public health team plan to conduct further research on the attitudes of the local residents.

In solving the rice-straw-burning problem, there is no single solution. Even if we succeed in converting rice straw into biofuel, eliminating open stubble burning completely, groundwater depletion will continue as long as rice cultivation continues. Making matters worse, climate change will reduce the water storage capacity of the Himalayan glaciers, further depleting groundwater. Under these circumstances, it is currently necessary to take measures to prevent unnecessary groundwater consumption as much as possible while continuing moderate rice cultivation. Innovation through the development of new technologies is important, but at the same time, as reported by PAU, more emphasis needs to be placed on education to ensure farmers accept new technologies as they are introduced and know how to use them properly.

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