AGRICULTURAL WASTE BURNING IN NORTHERN INDIA - ECONOMIC ANALYSIS AND FARMERS' PERSPECTIVES

by

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Abstract

Rice farmers in Northern India burn the rice "stubble" left in the fields after a harvest in order to clear land for the next sowing season. During several weeks in the burning season residents of the Indo-Gangetic Plain are exposed to levels of fine particulate matter that are ~100x greater than the annual WHO standard. Despite a ban on Agricultural Waste Burning (AWB), 9.96 million metric tons of rice residue was burnt in Punjab in 2018. Several 'active management' alternatives to AWB that include in-situ and ex-situ rice residue management are available to rice farmers. However, financial, logistical and institutional challenges make their adoption and impact inadequate.

This work focuses on the alternatives to AWB in the Punjab, particularly on (i) farmers' perspectives on available active management practices and challenges in adopting them (ii) the cost of residue management and how it influences practice (iii) role of government incentives. We expand on existing cost analyses of residue management processes by conducting semi-structured interviews with farmers and key experts to better understand how operational factors and cascading impacts may affect the profitability of different alternatives. These considerations include: timing of government subsidies, fixed bonus incentives, timely availability of required machinery, and pest implications. Our results show that given timely government incentives of a fixed bonus and subsidy on machinery, the cost of rice residue management through active residue management practices are comparable with residue burn. However, due to a short time window between cropping cycles, and wariness among farmers on the timely arrival of government subsidy, status quo of residue burn is more convenient and cost effective for farmers in Punjab. Farmers also highlight concerns of groundwater depletion in Punjab that residue management does not address, and highlight the need for crop diversification to address *both* issues of air quality and depleting

groundwater. These findings point to the importance of addressing AWB as more than simply a problem of residue management, but instead as part of a landscape of issues, including rice production in Punjab for national food security, mechanization, depleting groundwater, and short time duration for rice harvest.

Lay Summary

This thesis addressed the issue of Agricultural Waste Burning (AWB) that results in hazardous levels of air pollution in the Indo-Gangetic plain, especially in the winter months. The study takes into account farmers' perspectives on rice residue burning, available sustainable residue management practices, and government policies to promote sustainable rice residue management. Semi-structured interviews were conducted with 40 farmers in Punjab and 12 agronomic experts in Punjab, and data from existing literature was analyzed. It was found that given government incentives, sustainable residue management practices can be economically comparable to burning residue. However, farmers face various challenges in accessing to agricultural machinery and government incentives to shift away from residue burning. Crop diversification and shifting away from the rice-wheat cropping cycle in Punjab, can be a potential solution to the wicked problem addressing concerns of both air quality and depletion of groundwater.

Preface

This thesis is the original and unpublished work of Rudri Bhatt. An Ethics Approval from the UBC Behavioral Research Ethics Board was obtained for the purpose of primary data collection for the thesis (Certificate Number ##H19-01412 and #H19-01412-A001). I identified the research problem with the guidance and feedback of my supervisor Dr. Milind Kandlikar. The research was designed with the guidance of Dr. Milind Kandlikar, my committee member Dr. Amanda Giang, and the graduate research design course RES 502 taught by Dr. Stephanie Chang. The protocol for the semi-structured interviews were designed based on careful feedback of Dr. Terre Satterfield through the graduate survey design course RES 500X and Dr. Milind Kandlikar. I conducted the semi-structured interviews in-person through field-work in Punjab. All interviews were coded and analyzed on the qualitative data analysis software, NVivo. The cost analysis was carried out with thoughtful guidance and feedback from Dr. Milind Kandlikar and Dr. Amanda Giang.

This thesis is intended for journal publication, with Dr. Milind Kandlikar and Dr. Amanda Giang as co-authors.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

AWB – Agricultural Waste Burning

CHCs – Custom Hiring Centres

CNG – Compressed Natural Gas

FCI – Food Corporation of India

HP – Horse Power

IGP – Indo-Gangetic Plain

MNRE – Ministry of New and Renewable Energy

MSP – Minimum Support Price

NGT – National Green Tribunal

NPMCR – National Policy for Management of Crop Residue

Super SMS – Super Straw Management System

Acknowledgements

This thesis would not have been possible without the guidance and support of many people. Firstly, I want to express my gratitude to my Supervisor Dr. Milind Kandlikar for his insightful guidance and support. Thank you for encouraging me to ask tough questions, think outside the box and have confidence in my work. Thanks to my committee member, Dr. Amanda Giang, for her valuable feedback and accepting me into her lab group, LEAP. Milind and Amanda, you have both been very instrumental in shaping my master's journey and helping me through all my confusions and hesitations. My department, Institute for Resources, Environment and Sustainability has been a constant source of inspiration and motivation towards scientific thinking and contributing back to the society.

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Chapter 1: Introduction

This section presents the necessary background and problem landscape of the research problem of Agricultural Waste Burning (AWB) and reasons for treating it as a wicked problem. The contributions of this study to literature have also been presented along with the Research Questions.

1.1 Agricultural Waste Burning (AWB) and its contribution to air pollution

Exposure to air pollution is the single largest contributing factor to global mortality, responsible for 15% of all premature deaths and 275 million Disability-Adjusted life years in 2017 (Global Alliance on Health and Pollution, 2019). Agricultural Waste Burning (AWB) is a major contributor of air pollution in many countries including in South and South-East Asia (Gadde et al., 2009). Criteria pollutants such as Particulate Matter ($PM_{2.5}$), Carbon Monoxide (CO), Sulphur dioxide (SO_2), Nitrogen oxides (NO_x) as well as Volatile Organic Compounds (VOCs), and Polycyclic Aromatic Hydrocarbons are released into the atmosphere due to AWB (Awasthi et al., 2011; Jain et al., 2014; Hefeng Zhang et al., 2017). AWB is a major public health concern in India, and the second biggest cause of exposure to PM2.5, and estimated to be responsible for over 35,000 deaths (Maji, 2019). Each year, during the November/December AWB season, air pollution reaches catastrophic levels throughout the Indo-Gangetic plain.

The National Green Tribunal (NGT), a specialized forum for effective and speedy disposal of cases pertaining to environment protection in India, has imposed a ban on all open AWB and asked districts in Punjab to fine farmers who continue to burn residue (A. Singh & Zaffar, 2017). The ban had little effect on the practices of rice farmers in Punjab, and they continue open residue burning and run the risk of having to pay fine (N. Gupta, 2019). Farmers burn post-harvest rice stubble in defiance of national regulation, and in the face of stiff opposition from urban residents of the capital New Delhi.

1.2 Agricultural Waste Burning (AWB) as a wicked problem

Agricultural Waste Burning (AWB) in the Punjab is a result of a confluence of policies going back to the introduction of Green Revolution technologies in India (Frankel, 2015). Punjab, widely considered India's granary, and its agricultural sector faces a plethora of environmental challenges including; an alarming reduction of groundwater tables (Rodell et al., 2009) and hazardous air quality during the rice harvest season (Awasthi et al., 2011; Gupta et al., 2004; Sarkar, 2011; Singh, 2012). These concerns are intertwined. For example, policies to promote food production aimed at meeting National Food Security goals, have encouraged rice production with consequences for groundwater resources. As I elaborate later, policies aimed at containing the reduction in groundwater aggravated AWB and its effect on the ambient air quality of the Indo-Gangetic Plain (B. Singh et al., 2019). It is thus important to see AWB as part of the food-water-energy nexus in addressing the deeper socio-economic roots of AWB (S. Bhuvaneshwari et al., 2019). In this study we look at AWB as a wicked problem in Punjab Agriculture, recognizing that solutions targeted at sustainable crop residue management practices will only address part of the problem.

Rice is not a traditionally grown crop in Punjab. Since the Green Revolution, farmers in in the northwestern state of Punjab have been incentivized to grow rice as part of India's food security policies (Frankel, 2015). Guaranteed procurement of rice in Punjab at a Minimum Support Price[1] (MSP) by Food Corporation of India (FCI), budgeted by the national government, reduced the risks of rice cultivation and supported the expansion of rice production in Punjab (Niti Ayog, 2016). In the state of Punjab, rice production during the Monsoon or 'Kharif' season has increased from 227 thousand hectares in 1960-61 to 2845 thousand hectares in 2017-18 (Environmental Information System, 2018a). Figure 1.2.1 shows the trend in average yearly area and yield of rice cultivation in Punjab from 1960-61 to 2017-18 (Environmental Information System, 2018a, 2018b) Unlike other regions in India the Punjab agricultural sector is entirely mechanized. The Combine Harvester used to harvest the rice crop leaves behind large amounts of stubble and loose straw on the field (H. S. Sidhu et al., 2007). Furthermore, rice straw has a high silica content, making it a poor quality fodder for cattle unlike other staples such as wheat (Lohan et al., 2018; Na et al., 2014). In 2018, over 20 million metric tons of rice residue was generated in Punjab, of which almost 10 million metric tons was subject to open-air burning (Ministry of Agriculture and Farmers Welfare & Department of Agriculture, Cooperation & Farmers Welfare, 2019) .

[1] Minimum Support Price (MSP) for crops, declared before the sowing season, to protect farmers from price fluctuations and provide assured market at guaranteed prices. The Department of Agriculture and Co-operation, Government of India declared MSP on recommendations from the Commission for Agricultural Costs and Prices.

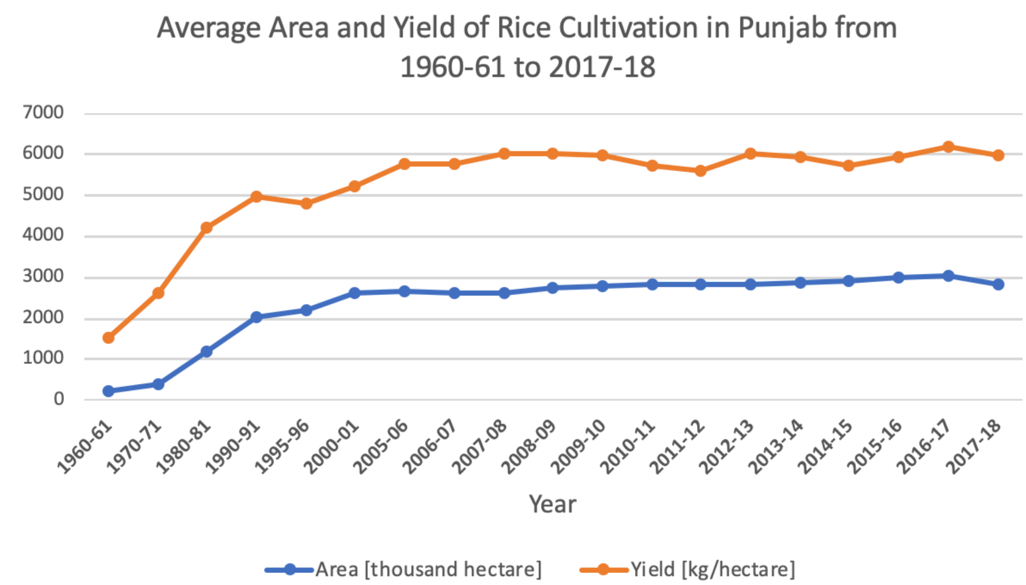


Figure 1.2.1 Average yearly area and yield of rice cultivation in Punjab from 1960-61 to 2017-18
Source: (Environmental Information System, 2018b, 2018a). Data source: Department of Agriculture, Government of Punjab

The rapid depletion of ground water in Punjab is a looming agricultural crisis. The provisioning of free electricity in Punjab for agricultural pumps, has over the past two decades, led to an increase in the number of groundwater "tube wells" (Singh, 2012). This has meant that groundwater is being drawn for flooded rice cultivation at a pace that is far greater than the recharge rate (Shah, 2009). The overuse of groundwater resulting from such subsidies led to a dramatic decline in ground water levels in the region. Between 1984 to 2016, a decline in groundwater level of more than 15m was observed in about 31% area, decline between 5-15m in about 33% area, and decline of up to 5m in about 21% area of Punjab. Rise of groundwater level was observed in about 15% area of Punjab (Ground Water Resources of Punjab State, 2018). Small-scale farmers unable to invest in the capital for tube wells, need to purchase water for irrigation from wealthier farmers. The benefits of free electricity are thus received disproportionately causing inequities in access to groundwater (Sarkar, 2011), with small scale farmers bearing the larger blunt of this problem.

In attempt to reduce the rates of groundwater decline in the state of Punjab, beginning in 2009 the Punjab government restricted paddy transplantation[2] that historically took place before the onset of monsoons in May, to later in the season, i.e, on or after June 20th (B. Singh et al., 2019). Figure 1.2.2 shows this shift in rice transplantation date. This policy is intended to increase the overlap between the growing season and the annual monsoon rains, and so to reduce the consumption of ground water. The subsequent delay in the harvest of rice crops in autumn leaves rice farmers in the region with a short turnaround of about two weeks to harvest the crop, manage the rice residue and sow the winter wheat crop. The optimum sowing period of the medium to short duration wheat crop grown in the region is 15th November, beyond which there is an estimated 0.7% yield reduction per day of delay (Ortiz-Monasterio R. et al., 1994). The policy to shift the growing season intended to protect groundwater levels, has had an unexpected consequence. The move of the harvest later in the year has meant that the burning of rice stubble is shifted into a post-monsoon season, with the peak of AWB shifted by two weeks (Jethva et al., 2019; Liu et al., 2020) from mid-October to early November. A shift to crop burning later in the season is coterminous with changing meteorological conditions over the Indo-Gangetic plain where reduced wind speed and temperature inversions might result in greater pollutant loading. Thus, a shift in growing season, along with an overall increase in paddy cultivation, coincides with 40% increase in total burning and ~50% increase in regional aerosol loading (Liu et al., 2020).

[2] Rice cultivation is a two-stage process. Seedlings are initially raised in a nursery that is 5−10% of the total farming area. They are then transplanted to the wet/puddled paddy field – this requires less seed, and controls weed, but also needs greater manual labor.

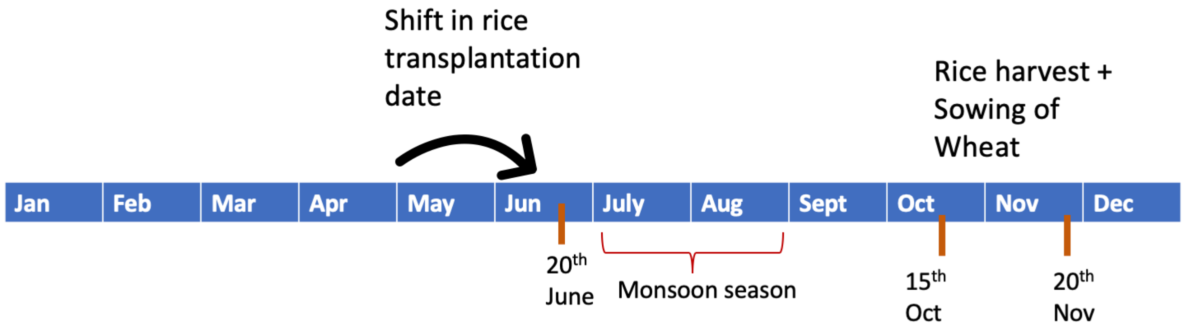


Figure 1.2.2 Cropping timeline for rice cultivation in Punjab

In recent years, facing precipitous decline in groundwater levels and catastrophic levels of air pollution from AWB, the Indian government has attempted to change farmer behavior related to AWB, and to incentivize other means of managing rice residue. In 2014, the Ministry of Agriculture and Farmers' Welfare, Government of India formulated The National Policy for Management of Crop Residue (NPMCR), which includes a list of directives to reduce AWB, such as the monitoring of agricultural fires, and facilitating the collection and transportation of rice residue. In order to increase the adoption of technological solutions to AWB, the Indian government also provides subsidy levels of 50% and 80% on capital costs of agricultural machinery to individual farmers and farmer groups respectively. Faced with increasing public concern over air pollution during the harvest season in 2019, the Supreme Court of India required the government to provide a fixed sum of money to incentivize small scale farmers to not undertake open residue burning. The National Green Tribunal (NGT), 2015 also provided several directives to curb air pollution due to AWB. Under the directives, open burning of residue is banned, and fines have been imposed (A. Singh & Zaffar, 2017). However, most policies are aimed at solely reducing AWB, without addressing the food-water-energy nexus at the centre of the problem.

1.3 Expected Contribution

In the past decade, concern towards air pollution from AWB has been increasing, with a concomitant increase in research on : the emissions from AWB and their contribution to ambient air pollution and resultant health impacts (Awasthi et al., 2011; Chandra & Sinha, 2016; Jain et al., 2014; Maji, 2019; Vadrevu et al., 2011; Hefeng Zhang et al., 2017) the analysis of potential sustainable alternatives to residue burning and its policy solutions including on comparison of profitable technological solutions (Shyamsundar et al., 2019) managing environmental resources by nexus thinking and active stakeholder involvement (S. Bhuvaneshwari et al., 2019), potential policy instruments for sustainable residue management (Lohan et al., 2018), economic analysis on the input-output and problems faced when adopting straw management technologies (B. Singh et al., 2019). However, many of these analyses tend to focus on 'top-down' techno-economic solutions. Farmers' perspectives on the proposed clean alternatives to AWB and government's proposed policy solutions, as well as 'on the ground' considerations such as access to technologies is largely missing from literature. This absence raises important questions of challenges faced especially by small and medium scale farmers on access and feasibility of adopting active residue management practices.

Shyamsundar et al. (2019) provides a comprehensive comparison between the net profits from 10 different residue management practices, including residue burn options, Happy Seeder, Baler and Rotavator options. Their cost analysis shows that the net profit of Happy Seeder based systems is 20% higher than common burning systems. Baler systems shows equivalent profits to burning systems, however less than Happy Seeder systems. Shyamsundar et al. (2019) also examine public costs related to residue burning: government subsidies, health and economic costs related to greenhouse gas (GHG) emissions, and groundwater depletion. They conclude that the seven nonburning residue management systems also have a lower social cost related to air pollution. The paper also discusses several adoption challenges with Happy Seeder including machinery capital cost, gaps in the supply chain and rental market, lack of knowledge, and limited incentives to shift to non-burn practices. My work draws important insights from the work of Shyamsundar et al. (2019) and builds on the importance and role of farmers' perspectives and government incentives in residue management.

Consequently, the research questions driving this study are as follows:

1. RQ1: What are farmers' perspectives on the available clean alternatives available and the challenges in adopting them?
2. RQ2: What are the costs of rice residue management, and how do they influence practice?
3. RQ3: What are farmers' perspectives to the targeted government incentives and are they effective in reducing agricultural waste burning?

In this paper, we:

1. Analyze how operational factors (such as farm size, timing and technology availability and choice) affect a farmer's decision to choose a rice residue management practice and to develop a decision flowchart to describe this process.
2. Use evidence from interview data and data from the published literature to develop a financial model for analyzing the costs of residue management consistent with the decision-making process of farmers operating at different scales (e.g. farm size), and with differential access to residue management options, and government policies.

3. Address how government policies are received by farmers in Punjab, analyze why government support to reduce agricultural waste burning is inadequate and examine some plausible alternatives.

1.4 Outline

This thesis consists of five chapters. Chapter 1 provided the introductory background on this AWB problem in Punjab. The remaining chapters are as follows: Chapter 2 consists of literature review of some of the relevant existing literature. Chapter 3 describes the research methodology for data collection and analysis, as well as the research questions of the study. Chapter 4 consists of farmers' decision making and cost analysis of rice residue management practices. Chapter 5 describes farmers' perspectives on current and potential government incentives. Finally, Chapter 6 presents the conclusions of the research.

Chapter 2: Literature Review

2.1 Ambient air pollution due to Agricultural Waste Burning (AWB) and its health impacts

Aerosols and other gaseous pollutants released due to biomass burning can have a potential impact on global air quality and atmospheric chemistry (Andreae & Merlet, 2001; Levine et al., 1995) Open burning of agricultural residue emits criterion pollutants such as Particulate Matter (PM2.5 and PM10), Carbon Monoxide (CO), Sulphur dioxide (SO_2), Nitrogen oxides (NOx), Ammonia (NH_3) as well as Volatile Organic Compounds (VOCs), and Semi-Volatile Organic Compounds (SVOCs) (Jain et al., 2014; Mittal et al., 2009; H Zhang et al., 2008). Rice is harvested at the onset of winter in North-western India and its residue is burnt in the winter months while crop residue of the wheat crop is burnt in the summer months. Agricultural waste, namely straw and stubble left over on the fields after harvest is burnt to clear the field rapidly and inexpensively (Jain et al., 2014). Ambient concentration of PM2.5 and PM10 vary during the winter and summer months. The concentrations of PM10 and PM2.5 increased to 66 $\mu g/m^3$ and 78 $\mu g/m^3$ (microgram per cubic meter) respectively during the winter months and 51 $\mu g/m^3$ and 43 $\mu g/m^3$ respectively during the summer months (Awasthi et al., 2011). There is also spatial variation in PM2.5 concentration across India. The modelled annual mean PM concentrations in the Indo-Gangetic Plain (IGP), ranging from 50 – 150 $\mu g/m^3$, is two to four times the PM concentration in other parts of India (Brauer et al., 2012; Maji, 2019; Venkataraman et al., 2018). Figure 2.1.1, taken directly from Jethva et al., (2019) shows temporal and special long-term (2002 – 2006) distribution of fire counts and aerosol loading over most of the Indian subcontinent. The temporal distribution shows the increased concentration of fire counts and aerosol loading in November as compared to October, as well as the special concentration in the IGP. During residue burning season, a large portion of the recorded PM2.5 concentration in the national capital city of New Delhi can be attributed to smoke from AWB (Cusworth et al., 2018). In addition, higher amounts of Polycyclic Aromatic Hydrocarbons (PAHs) and toxic trace including lead (Pb), cadmium (Cd), nickel (Ni) and arsenic (As) are present in fine particulate matter (Makkonen et al., 2010). Further, incomplete combustion of or crop residue during open burning increases the emission of smoke and particulate matter.

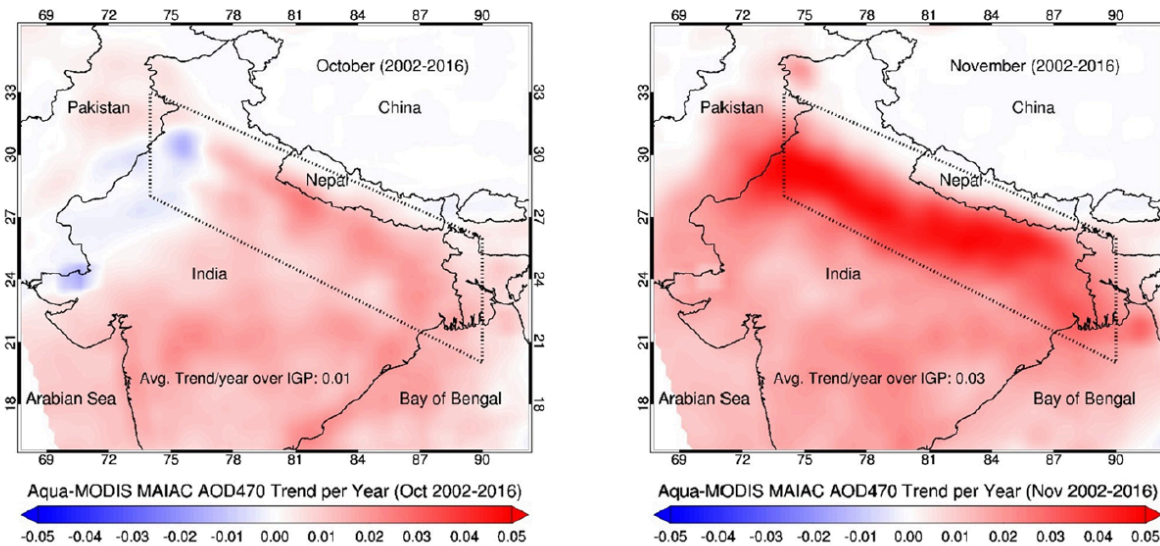


Figure 2.1.1 Long-term trends (2002 – 2016) in spatial patterns for fire counts and aerosol loading over most Indian Subcontinent for the months of October (left) and November (right).
Source: (Jethva et al., 2019). Fire counts and aerosol loading is shown in box

The air pollutants released through AWB can cause severe health impacts. Long term (few years) and short term (few hours to weeks) exposure to fine particulate matter less than 2.5 μm (micrometer) can cause premature mortality due to respiratory and cardiovascular diseases (Brauer et al., 2012; Brook Robert D. et al., 2010; Burnett et al., 2014; Makkonen et al., 2010). Globally, 3 million premature deaths were attributed directly to PM 2.5 pollution in 2017, of which 673,000 premature deaths (second highest globally, after China) were estimated in India (Health Effects

Institute, 2019). Sulphur oxides can oxidise to sulphuric acid that causes lung disorders, and oxides of nitrogen can cause respiratory disease especially for children (Pandey et al., 2005) .

2.1.1 Increase in rice production in Punjab

Punjab has two major cropping seasons. In the Rabi season from November to April, farmers grown wheat historically and continue to do so. In 2017-18 3,480,000 Hectares of wheat were grown in Punjab (Department of Agriculture, 2018). In the Kharif season that lasts from May to November, farmers now primarily grow rice, though this has not always been the case. Rice is not a staple food for the people of Punjab, nor was it traditionally grown in Punjab. Due to past agricultural success and irrigable land, the Green Revolution in the 1960s saw an increase in rice production in Punjab through government-sponsored programs, making Punjab the 'rice bowl of India (Frankel, 2015; Rang et al., n.d.). Punjab has seen an increase in rice production from 227 thousand hectares in 1960-61 to 2845 thousand hectares in 2017-18 (Environmental Information System, 2018a). Fertilizer responsive rice varieties and improved irrigation aided in the expansion of area under rice cultivation in Punjab between 1960 to 1990s (H. S. Sidhu et al., 2007) occupies only 1.5% of India's geographical land area, it contributed 24.2% in 2014-15 to the government procurement of rice used for subsidized distribution to the poor (Grover et al., 2016). The use of Minimum Support Price (MSP), that fixes a minimum price for certain crops prior to sowing season by the Government of India is an important reason for an increase in rice production in the state (Niti Ayog, 2016). Prior to the rise in rice production, maize, cotton and pulses were the primarily produced crops in Punjab (Jamwal & IndiaSpend com, 2016).

2.1.2 Mechanisation of rice cultivation and cost of labor

Cultivating and harvesting rice in Punjab has become increasingly mechanised over the years. Traditionally done manually, most farmers now use a Combine Harvester to harvest the rice crop, which is practice that leaves behind large amounts of residue as stubble on the field (Ahmed et al., 2015). Rice stubble is 30-60 cm high is left on the field, along with large loose straw (H. S. Sidhu et al., 2007). Due to this substantial amount of residue, the preferred approach of farmers is to burn the rice residue while preparing the field for wheat sowing season. In an attempt to reduce the number of fires, the Punjab Pollution Control Board issued an advisory in 2018 making it mandatory to mount Super Straw Management System (Super SMS) on the Combine Harvester (Punjab Pollution Control Board, 2018). The Super SMS cuts the rice straw coming out of the Combine Harvester and spreads it evenly on the field making it easier to manage it sustainably. However, the Super SMS devices were attached to about 1000 of 7500 Combine Harvesters covering only 1.6% of the total paddy harvesting in the state with Super SMS (Chaba, 2017).

The agricultural work force in Punjab mostly consists of migrant labor from neighboring states of Bihar and Uttar Pradesh. Due to increased mechanisation of rice harvesting in Punjab and employment programs like the Mahatma Gandhi National Employment Act (MNREGA) in neighboring states, the influx of agricultural labors from Bihar and Uttar Pradesh to Punjab has reduced (Sirhindi, 2019). This has resulted in an increase in the cost of agricultural labor during the rice harvest season. (Sharma, 2018). With the amount of rice residue left by the Combine Harvester on the fields and increase in the cost of labor, farmers find it both convenient and economical to burn residue to clear and prepare their fields for the next crop.

2.1.3 Depletion of groundwater in Punjab

70% of all freshwater withdrawals and 90% of all water consumption around the world happens for irrigation purposes (Siebert et al., 2010). In India, groundwater is a major source of water for irrigation. 49% of rice production and 72% of wheat production is supported through groundwater irrigation in India (Smilovic et al., 2015). 37% of worldwide use of groundwater for irrigation purposes is in India alone (Siebert et al., 2010). This has led to a rapid decrease in groundwater resources, especially in the North-western states of India. The replenishment of groundwater aquifers from irrigation is less than the rate of withdrawal, with most of the irrigated water being lost through run-off or evapotranspiration (Rodell et al., 2009). Out of the 138 groundwater blocks in Punjab state, 109 blocks are over-exploited, 2 blocks are critical, 5 blocks are semi-critical and only 22 blocks are safe[3] (Ground Water Resources of Punjab State, 2018).

With assistance provided by government's through subsidised power supply and falling cost of pump installation, individual farmers dig tube wells on their farms throughout the region over the past two decades (B. S. Sidhu et al., 2020). Availability of free electricity for agriculture in Punjab since 1997, and irrigation needed for flooded paddy cropping, have rapidly caused the groundwater level to drop to 150-200ft in most blocks in Punjab (Vasudeva, 2019). In 2009, the Punjab state government enacted The Punjab Preservation of Subsoil Water Act, 2009 that prohibited farmers from sowing nursery of paddy before 10th May and transplant paddy before 16th June or such other day as notified by the State Government (The Punjab Preservation of Subsoil Water Act, 2009). This law was meant to align paddy cultivation in Punjab with the on-set of

[3] Categorisation of groundwater quantity is defined by stage of groundwater extraction as follows: ≤70% - Safe, > 70% to ≤90% - Semi-Critical, > 90% to ≤100% - Critical, >100% - Over Exploited

monsoon season in order to conserve groundwater resources by reducing water demand and controlling the amount of water lost due to evaporation.

2.2 Available technological solutions to AWB

2.2.1 In-situ residue management

In-situ incorporation of rice residue is the process of incorporating the rice residue back into the soil after harvesting the rice crop. Cereal crop residue has stored nutrients, with 25% of nitrogen (N) and Phosphorus (P), 50% of sulphur (S), and 75% of potassium (K) (P. Kumar et al., 2015). Rice straw in particular contains 39 kg/ha N, 6 kg/ha P, 140 kg/ha K and 11 kg/ha S (H. S. Sidhu et al., 2007). Further providing paddy straw as mulch can have substantial savings in irrigation and fertilizer. One study suggests 6 g of N and 0.8 g of P are added to the soil per kg of rice straw resulting in 15-20% savings in total fertilizer use (P. Kumar et al., 2015).

There have also been various inventions to help in-situ residue management or rice residue. Scientists from Australia and India at the Australian Council of International Agriculture Research (ACIAR) developed the Happy Seeder. The Happy Seeder machine is a combination of a seed drill and stubble mulcher, enabling farmers to simultaneously sow wheat crop while cutting the stubble it as mulch (H. S. Sidhu et al., 2007). Scaling up the production of Happy Seeders can make them more affordable, bringing down their price from INR 130,000 to INR 100,000 per machine (Somanathan & Gupta, 2017). 56 Indian National Rupee (INR) = 1 Canadian Dollar (CAD). This exchange rate is maintained throughout the thesis. Further, training camps and campaigns by the Krishi Vigyan Kendras (KVG) or agricultural extension services, have resulted in a higher adoption of Happy Seeder in some villages in Punjab (Jaidka et al., 2020). However farmers have expressed problems of rodent attack, non-decomposition of straw and non-availability as major concerns with the Happy Seeder (J. M. Singh et al., 2019). Other machinery such as the Rotavator, Disc Harrow, and Cultivator can be used for wet and dry mixing of rice residue into the soil after harvest (J. M. Singh et al., 2019). These appliances come with varying constraints of availability, access and costs.

2.2.2 Ex-situ residue management

Residues of rice, wheat, maize and sugarcane are rich in lignocellulose biomass that contains cellulose, hemicellulose and lignin that in principle can be used as raw material for the production of biofuels (S. Bhuvaneshwari et al., 2019), with several pilot studies that attempt to show feasibility. For example, a case study in Thailand showed that using rice straw for power generation is comparable to that of using other biomass and switching from the existing coal powered boilers to rice straw can amount in cost savings of feedstock supply (Suramaythangkoor & Gheewala, 2010). The rice husk ash, rich in silica content, produced as a by-product of gasification and combustion processes has applications in cement and ceramic manufacturing (Zain et al., 2011). Rice straw also has applications in paper mills as a substitute for pulp (P. Kumar et al., 2015). In practice, however, the use of rick straw for power generation and other industrial applications has been limited. First, since rice straw is a geographically dispersed and low density material, the cost of collection, transportation and processing of the rice residue can surpass the benefits gained from using it as raw material (S. Bhuvaneshwari et al., 2019). Analyses also show that it is not always economically feasible to generate power from rice residue (G. Kumar, 2017) given the costs of production vis-à-vis the price of power.

Chapter 3: Research Methods

A mixed methods approach was carried out in order to understand both the tangible costs and intangible constraints (such as access to technology) faced by farmers that are associated with sustainable management of rice residue. Mixed methods helped in quantifying the cost of residue management and field preparation through cost analysis, while farmer and expert interviews added nuances of factors involved in residue management decision-making for farmers including cost and access to technology, and the role of available government policies. There are various existing alternatives to AWB in literature. However, we wanted to understand the feasible technological alternatives to AWB and the required conditions for their operation, from rice farmers in Punjab directly without imposing our own assumptions. Thus, semi-structures interviews helped highlight the commonly used rice residue management methods, the factors influencing farmers' decision making (RQ1), costs associated with the residue management methods (RQ2), and the role of government policies (RQ3) as narrated by farmers in Punjab. The interviews were conducted in December 2019 with 40 farmers in the North Indian state of Punjab.

The interview protocol, attached in appendix A.1, contained questions related to technological alternatives to AWB and their operating conditions (RQ1), financing/costs of field preparation for the next season (RQ2), and perceptions of government policies and their impacts on residue burning (RQ3), in addition to broader questions about their farming practices. 12 farmers were interviewed from Ludhiana district, 14 from Patiala district, 8 from Bhatinda district, and 6 from various other districts in Punjab interviewed at a farming expo. One participant was a wage-earning farm worker, 38 participants cultivate rice on the land they own or lease, and one farmer cultivated vegetables along with rice as part of contract farming. 38 interviewed farmers also cultivate wheat as the primary crop in the Rabi season after harvesting rice, while one farmer cultivates vegetables, potato and maize for the entirety of his field in the Rabi season. 15 of the interviewed participants cultivate on farms of 10 acres or less.

Semi-structured interviews were conducted with 12 agronomic experts; questions focused on the scope of in-situ and ex-situ residue management practices and the perceived challenges faced by farmers in their adoption (RQ1), responsibility and role of central and state governments to support farmers in reducing residue burning (RQ3), and questions addressing long-term solutions to regional air quality, depleting groundwater resources, and continued production of rice in Punjab for national food security. See appendix A.2 for questionnaire.

In answering RQ1, semi-structured interviews were conducted where farmers were asked about the residue management practices they use and the factors that influence the decision-making process. Farmers expressed the pre-requisites and operating conditions for some of the common active residue management practices, including using Happy Seeder, Rotavator, Reversible Plough, Baler, and allowing residue to decompose in-situ in water. The interviews helped bring forward the infrastructure constraints (access to heavy tractor and required machinery), institutional constraints (short time window to manage rice residue, continued cultivation of rice especially long duration rice variety) and perceived consequences (pest attacks after using Happy Seeder and increased cost of diesel) when adopting of active management practices. Figure 4.1.1 shows a flowchart representing farmers' decision making as a result of these constraints. The flowchart also highlights the conditions under which farmers expressed residue burning to be the most favourable residue management practice. Expert interviews further expanded on the scope of in-situ and ex-situ residue management practices and infrastructure required to improve access to agricultural machinery in a timely manner.

In answering RQ2, a cost analysis of six most common residue management practices that emerged from farmer interviews, was carried out to compare the cost of field preparation bore by farmers in each residue management practice mentioned in section 4.2. The cost of field preparation includes cost of harvesting rice with a combine harvester (with or without Super SMS), cost of residue management including diesel and labor costs, and cost of cultivating the next wheat crop as a result of the residue management method chosen including fertilizer and insecticide. The cost of field preparation were developed from the semi-structured interviews as well as synthesised from secondary data (Shyamsundar et al., 2019) to fill in some gaps in the primary data. Since the evidence of costs is self-reported by farmers in the semi-structured interviews, it is not a survey of a representative sample. However, the method allows us to capture a more realistic picture and provides the nuances of various cost elements and government policies available.

In answering RQ3, farmers were interviewed about the role and effectiveness of current and prospective government policies. Farmers were asked to choose preferred government incentive among full subsidy on machinery, fixed bonus incentive, assistance with residue collection and transport, and MSP on crops other than rice. Farmers expressed challenges and shortcomings of current government policies for subsidy on machinery, delay in rice transplantation date, and lack of guaranteed procurement of crops other than rice. Both farmers and experts also highlighted the importance of government subsidies and incentives at various stages of crop cultivation, including choice of crops cultivated and residue management. Expert interviews further expanded on the institutional changes required and the responsibility of central and state governments in addressing AWB.

3.1 Sampling Strategy

Convenience sampling was used to recruit participants for on-site interviews in Ludhiana, Patiala and Bhatinda districts of Punjab. A random sampling was followed to recruit participants at the PDFA International Dairy & Agri Expo held in the city of Ludhiana to recruit farmers participating from all around Punjab. Punjab is divided into 22 districts, of which Ludhiana has the second largest area under paddy cultivation (259,000 hectares) and Patiala the third largest, (232,000 hectares), while Bhatinda has 152 thousand hectares under paddy cultivation (Ministry of Environment, 2019). Ludhiana is also home to Punjab Agriculture University, that conducts research on agricultural technologies and crop varieties and helps spread awareness amongst farmers. The interviewed participants represent variation in farm sizes, with farm size ranging from 4 acres to 125 acres (mean = 21 acres).

The sampling of farmers for the study was restricted to convenience sampling due to constraints in recruiting farmers through established contacts and a farmers' dairy co-operative in Punjab called Verka. In addition, AWB is a sensitive issue among farmers in Punjab, especially in December, just after the annual rice harvest, as there were many official complaints against farmers who have practiced residue burning. It was thus important to build trust with each participant and be considerate of their concerns. The sample size for this study was and restricted to three of Punjab's 22 districts; a sample size covering the rice producing districts of Punjab would make it a more representative sample. Conducting interviews with other stakeholders, such as machinery manufacturing companies, agricultural labors, commission agents (locally known also known as arthiya) and local and central administration could provide a broader range of perspectives to the complex issue of AWB. Despite these limitations, conducting semi-structured interviews with farmers in Punjab provided valuable insights into agricultural practices undertaken, especially small and medium scale farmers, and the factors on ground that impact their decisions. The interviews also helped fill the gaps between the common theoretical perception of availability (of agricultural machines and government incentives) and practical constraints of access.

The 12 agronomic experts included policy makers and agro-economic, public policy, and botany experts from Punjab Agricultural University, Punjabi University, and Haryana Pollution Control Board.

3.2 Interview Protocol

Semi-structured farmer interviews were audio recorded by the researcher upon receiving verbal consent from farmers who expressed interest to participate in the study. All interviews were conducted in Punjabi and Hindi which are local languages, and then translated into English. Suitable experts were sent a Letter of Intent detailing the study. A Consent form was sent to participants who expressed interest in participating in the study. The semi-structured interviews were audio recorded after receiving verbal consent from the participants. All interviews but one, were conducted in English. One expert interview was conducted in Hindi. The interview questionnaire for farmer and expert interviews are attached in appendix A.1 and A.2 respectively.

3.2.1 Farmer Interviews

The questionnaire for farmer semi-structured interview was generated to cover three main themes around AWB: environmental factors, techno-economics of residue management, and farmer perceptions towards government policies. Complete questionnaire attached in appendix A.1. To address each theme, farmers were asked questions about:

- **Environmental Factors:** Impacts of AWB on air quality, soil quality, fertilizer requirement and water consumption for consecutive crops.
- **Techno-economics of Residue Management:** Residue management methods including current residue management practices, available in-situ and ex-situ practices, and perceived best residue management practice. The interviews explored questions regarding access to high horsepower (HP) tractor, agricultural machinery, cost of diesel and labor and time required to manage residue through both active management and status quo (burn).
- **Farmer perceptions towards government policies:** Perceptions and preference for government policies aiding sustainable residue management including subsidy on machinery, fixed bonus incentives, assistance with residue collection, and reliable procurement at fixed rate for crops other than rice and wheat.
- **Other Polices:** Concerns about depleting ground water level and a need for crop diversification emerged from farmer and expert interviews. Questions explored farmers' interest in cultivating crops other than rice and wheat in Punjab, and challenges faced in doing so

3.3 Analysis

3.3.1 Farmer Interviews

To address RQ1, factors influencing decision-making on post-harvest rice stubble management such as farm size, access to technology, time availability, and management costs for farmers in

Punjab were drawn from the semi-structured interviews. In order to do this, the following steps were followed:

1. The most common residue management practices used by farmers and the conditions under which they are operated were identified and elaborated upon.
2. The variables, such as access to technology, cost of operation, and pest implications that influence farmers' decision making of residue management practices were assessed.
3. The final residue management practice, the condition of operation, and variables influencing each decision were then aggregated into a flow chart that demonstrates the process used by farmers in decision-making of rice residue management.

To address RQ2, Cost of rice residue management and field preparation for the upcoming cultivation done either through purchase or rent of machinery or through residue burning were synthesized from the existing literature and farmer interviews. The detailed steps describing undertaken for the cost analysis is described in section 3.3.3.

To address RQ3 on the role of government incentives and their effectiveness to stop residue burning, was analysed form farmer and expert semi-structured interviews.

- Farmers' preference to one government incentive over the other was assessed along with their reasons. Further, government policies aimed at overcoming financial and logistical challenges for adoption of active residue management were identified from farmer interviews.
- A deeper analysis of the required infrastructure and institutional change supported by government policies was compiled from expert interviews.

The semi-structured interviews were translated and transcribed into English from Punjabi and Hindi. The qualitative data analysis software, NVivo, was used to code the interviews on the following primary themes:

3.3.2 Expert Interviews

Through expert interviews, we triangulated data from farmer interviews on technological solutions to AWB, field preparation costs for residue management, and policy solutions addressing AWB as a wicked problem. Expert interviews provided insights into the nuances of various residue management practices and the actual 'on the ground' implementation of policies aimed at addressing AWB. Upon receiving verbal consent from experts who expressed interest in participating in the study, interviews were audio recorded and coded in NVivo on the following primary themes:

- The scope of in-situ and ex-situ residue management practices.
- Groundwater conservation and externalities of Preservation of Subsoil act, 2009 on AWB
- Government policies required to incentivise sustainable residue management practices and penalise AWB.
- Mechanism of crop diversification in Punjab and challenges to shifting away from the rice-wheat cropping cycle.

3.3.3 Cost Analysis

A cost analysis of the field preparation costs when using the six residue management practices was carried out to answer RQ2 on the cost of rice residue management and how it affects practice.

Primary cost data was extracted from farmer interviews and secondary data was extracted from Shyamsundar et al., (2019) . Secondary data from existing literature was used to ensure that the primary data was comparable to costs of field preparation and residue management in existing literature and complement primary data where costs was missing or insufficient. The capital costs and available subsidy for purchase of Happy Seeder, Rotavator, Reversible Plough, and Straw Chopper & Mulcher for individual farmers are benchmark costs taken from Report of the Committee on "Promotion of agricultural machinery for in-situ management of crop residue in states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi (Ministry of Agriculture and Farmers Welfare & Department of Agriculture, Cooperation & Farmers Welfare, 2019). The rental capital cost for Rotavator + other machinery is the mean of primary cost data extracted from farmer interviews and secondary data, while rental capital cost of Happy Seeder and Baler are from primary data. Operation costs of fertilizer when using Rotavator + other machinery and residue burn, labor and insecticide costs when using residue burn management practice are a mean of both primary and secondary data. All other rental capital and operating costs have been derived from primary data (farmer interviews).

The following steps were followed to ensure an integrated cost analysis of field preparation by residue management practices:

1. Farmers were asked to detail the cost of residue management (including cost of machinery rent, diesel, and labor) and the cost of cultivation as a result of the residue management practice followed (including cost of fertilizer and insecticides). Farmers also detailed accounts of receiving government incentives such as subsidy on machinery and fixed bonus incentive for active residue management.

2. A comprehensive data set was then produced with primary data from farmer interviews and secondary data, where required.
3. The lifetime of 10 years is assumed for agricultural machinery. Thus all costs extracted from primary and secondary data were extended to 10 years, accounting for two machinery repair costs for the machinery purchase alternatives. Assumed inflation rate is 3.34%. It is assumed that farmers make 20% down-payment of capital costs when purchasing the machinery and request a loan from banks at the 7% interest that is paid off in the first five years. It is further assumed that farmers receive subsidy on purchase of machinery at the end of first year, based on responses from farmers. In order to compare the total cost incurred by farmers in each of the six residue management practices, the Net Present Value (NPV) is calculated with a discount rate of 10% over 10 years. The NPV is then annualized. The final annualized costs for each residue management practice are displayed in figure 4.3.1 through figure 4.3.7.
4. A sensitivity analysis for the costs incurred by a farmer in the first year is conducted to capture the variance in the cost for each residue management practice. In order to do this, the minimum, maximum and mean costs for the capital and field preparation costs are linearly added to obtain the total minimum, maximum and mean costs by each residue management practice. In case of single data point or no measured variation in data, 10% positive and negative cost variation has been assumed. The variation in total cost for each residue management practice is displayed in figure 4.3.8.

Chapter 4: Rice Residue Management - Farmers’ Decision Making and Cost Analysis

This section presents the results of our mixed methods approach. Section 4.1 presents the factors that influence the adoption of a rice residue management practices for farmers in Punjab; interviews with farmers are used to develop a flowchart that characterizes the decision-making on residue management. The flowchart presents an answer to RQ1, viz., farmers’ views on options available for residue management and barriers to decision-making. Section 4.2 presents a description of the six different rice residue management practices employed by farmers as they prepare their fields for the next cropping season. These six options emerged from farmer interviews. Section 4.3 presents a cost analysis comparing the field preparation costs for the six residue management practices, with and without government incentives. The analysis presents private field preparation costs to individual medium to large scale farmers (i.e., a 15-acre holding) and small-scale farmers using annualized Net Present Value calculations over a 10-year period.

4.1 Rice residue management decision-making process

The technologies used for residue management include:

- The Super Straw Management System (Super SMS) that is mounted over a Combine Harvester that chops the straw coming out of it and spreads residue evenly throughout the field, making it possible to use active management practices.
- A Happy Seeder, is a device that is mounted on a tractor rated at minimum value of 45 Horse Power, is a seed drill attached on a straw management unit that cuts the rice stubble and spreads and straw, after the wheat seed is drilled into the ground. (H. S. Sidhu et al., 2007).

- A Super Seeder, introduced in 2018, is a device that mounted on a tractor, and rated at minimum value of 65 HP. It is a more powerful version of Happy Seeder. (Shali, 2019)
- A Reversible Plough is a hydraulic cylinder based ploughing machine that operates on a tractor ranging 45 to 90 HP (Pushpak Super Hydraulic Reversible Plough, n.d.). It incorporates the risk stubble into the ground, removing the need to burn the crop.
- Finally, a Baler collects the residue into bundles making it easy to transport.

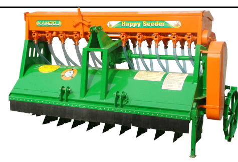
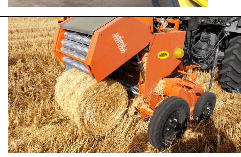
Machine		Function
Combine Harvester		Used to harvest rice residue
Combine harvester with Super SMS		Mounted on Combine Harvester to cut straw coming out of it and spreading it evenly in the field, making active in-situ residue management easier
Happy Seeder		Seed drill that also cuts rice stubble and replaces it over as mulch after sowing the wheat crop
Rotavator		Tilling machine. Often comes with seed drill
Reversible Plough		hydraulic cylinder based ploughing machine
Baler		Collects residue into bundles, for ex-situ residue management

Table 4.1.1 Description of common agricultural machines

Small vs. Large Farms: All machinery used for residue management such as (i) Super SMS mounted on a Combine harvester (ii) Happy Seeder, (iii) Super Seeder and (iv) Baler require high power tractors (>45 HP) to operate. Thus, the adoption of sustainable residue management is predicated on the availability of and access to a high horsepower (HP) tractor. It is feasible for farmers cultivating on medium to large farms (10 acres of more) to purchase a heavy tractor of 50 horsepower or more, whereas purchasing a high HP tractor may be beyond the economic capacity for a small scale farmer, i.e., farmers operating on land less than or equal to 5 acres. Since machinery such as Super SMS, Happy Seeder and Baler require high HP tractors to operate, the use of these machinery is limited to medium to large scale farms. Thus, access to a high-power tractor is a limiting first step in the decision to burn agricultural residue. Those without such access tend to burn the residue. Marginal to small scale farmers, that lack access to a high HP tractor are unable to use a Super SMS with their Combine Harvester when harvesting the rice crop. In such cases, a sustainable residue management practice available is the use of Rotavator in combination with a Reversible Plough or Mulcher on the field in order to incorporate the residue in-situ, a process that takes can several iterations. However, the process of repeated use of a Rotavator can result in high diesel consumption and labor costs per acre, resulting in a decision to burn the rice residue. Thus, for small farmers, those with fields less than 5 acres, burning of stubble is the easiest option.

Figure 4.1.1 is a flow chart that describes how the farmers' decision-making process for rice residue management practices are influenced by operational factors such as farm size, access to technology, time available and cost. Below we provide a discussion of the key elements structuring decision-making.

Timing and Performance Constraints: An important factor in residue management is the availability of time between rice harvest and sowing the next crop. Sowing short duration rice variety enables farmers to harvest the rice crop early, giving them a longer time window to manage the residue before sowing the next crop, primarily wheat or potato. Given more than 10 to 15 days between harvesting rice and sowing the next crop, and when provided with reliable electricity supply, farmers can fill the post-harvest fields with water and allow the rice residue to decompose and mulch. This makes it easy to incorporate the rice residue into the fields with a simple Rotavator or Reversible Plough, without having the need to burn the residue. However, the commonly cultivated variety by those interviewed sample size, is Pusa-44, a high-yield and long growing hybrid that leaves farmers only 10-15 days to manage the residue and prepare the field. Thus, a farmer growing long duration rice variety is very likely to burn the residue on the field in order to clear the field quickly. Many farmers as well as experts raised concerns of insect and pest attacks after using Happy Seeder. In such an event the farmer may have to sow the wheat crop a second time using a Rotavator, resulting in further losses due to delayed sowing of wheat crop.

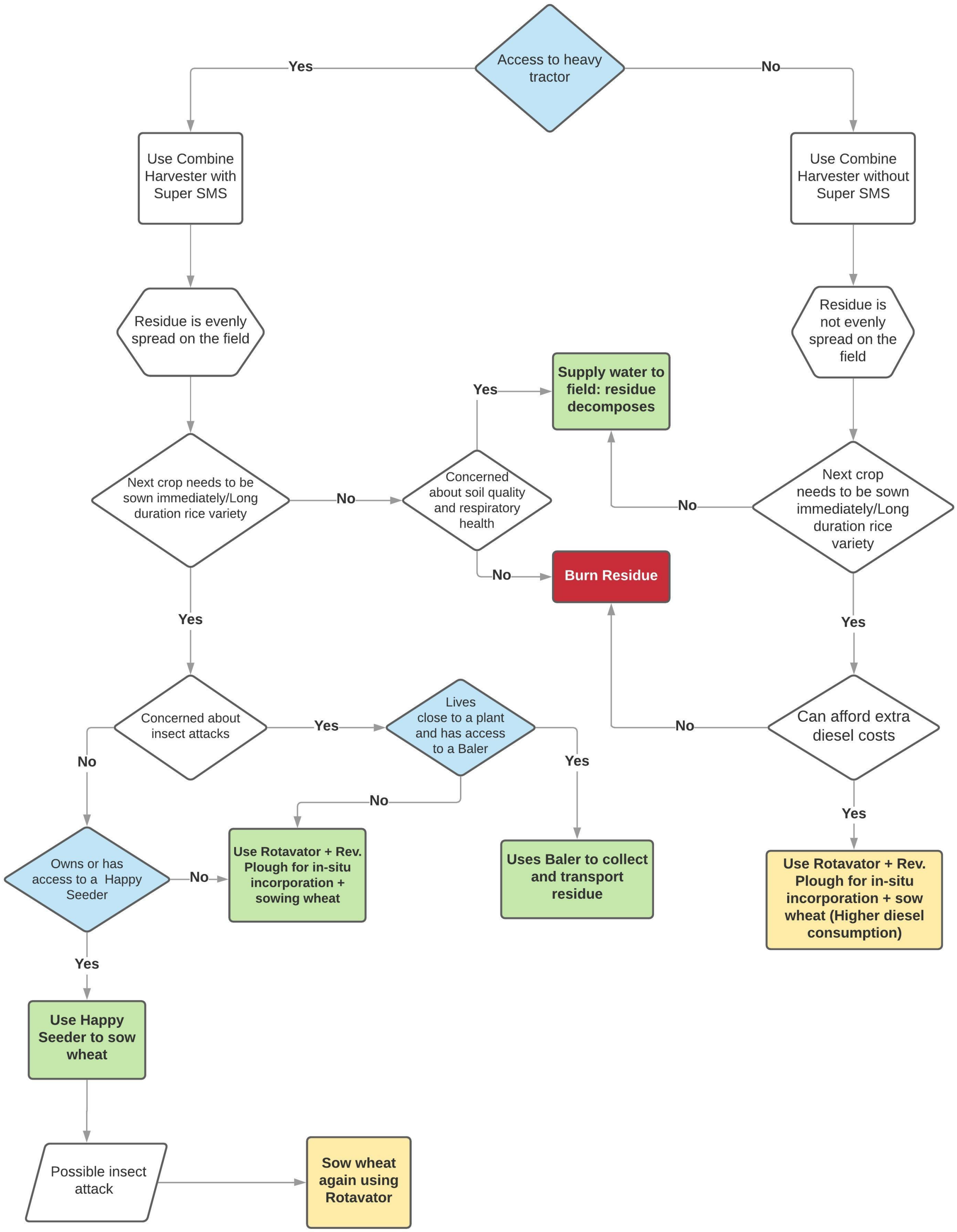


Figure 4.1.1 Farmers' rice residue management decision-making process
The final processes in green are the desirable outcomes, processes in yellow represent the outcomes that are undesirable for farmers due to extra costs and re-sowing of wheat causing a delay, and status quo of residue burn is in red as it is an overall undesirable outcome in terms of environmental impacts.

Availability/Rent vs. Purchase: Marginal and small-medium scale farmers, often need to rely on the availability of agricultural machines on rent through farmers co-operatives, Custom Hiring Centres (CHCs), or wealthier farmers in the village. This is particularly challenging given the short time period available to manage the residue and clear fields to sow the wheat crop. Government incentives aimed at reducing AWB can offset some of the costs of field preparation for active management. Government subsidies for the purchase of selected agricultural machinery from licensed manufacturers makes it feasible for medium-large farmers to purchase these machineries. Eight or more farmers can also apply for group (at 80% of capital cost) subsidy. Formation of farmer societies has been encouraged by the government as this increases the machinery purchasing capacity of farmers by shared ownership, bringing down their cost of active residue management. Shared ownership of agricultural machinery can help increase the financial viability of residue management. Farmer societies can also rent out unused machinery to other farmers in the village, adding to their income as well as increasing the machinery rental market in the village.

4.2 Residue Management Options: Description and Cost Analysis

The following rice residue management practices have been considered for the cost analysis of field preparation costs. The sustainable residue management practices through purchase and rent of Happy Seeder, purchase and rent of Rotavator + Other Machines, and rent of a Baler are termed as termed 'Active Management' options. Full or partial burning of residue is termed as a Status Quo option. Table 4.1.1 shows a picture representation of the machines considered in this analysis along with a short description. Table 4.2.1 details the six rice residue management scenarios that have been explored in this thesis. These six scenarios emerged as the most common rice residue management practices from the farmer interviews.

It is important to note that of the six rice residue management alternatives considered, not all are available to small farmers. Based on the flow chart in Figure 4.1.1 the ability to choose between these alternatives depends on the access to these machines, through purchase or rent. Active Management through purchase of Happy Seeder and Rotavator + Other Machinery is considered for farms with an average assumed farm size of 15 acres or greater due to their economic capacity to purchase machinery. Active Management through renting Baler and Rotavator + other machinery is considered for small to medium scale farmers. Agricultural machines are available on rent from farmer groups and cooperatives, other farmers in the village, and Custom Hiring Centres (CHCs).

Other costs include: a 2% salvage value return at the end of a machine's life, diesel, labor, fertilizers and insecticides for both active management and status quo alternatives. Other assumptions include a rate of return of 10% and an inflation rate of 3.4%. For the purchase of machinery, we assume a 20% down payment of capital cost, while the remaining amount is provided through an 80% bank loan at 7% interest payable in 5 years.

Residue Management Method		Farm size	Capital cost included	Government incentives	Other considerations/ requirements
1	**Purchase - Happy Seeder**	Medium to large scale	Combine Harvester with Super SMS	50% subsidy	High HP tractor required
			Happy Seeder	Fixed bonus	Machine lifetime 10 years; repair costs included
2	**Purchase - Rotavator + other Machinery**	Medium to large scale	Combine Harvester with Super SMS	50% subsidy (except on Rotavator)	High HP tractor required
			Rotavator	Fixed bonus	Machine lifetime 10 years, repair costs included
			Mean of Reversible Plough, Straw Chopper & Mulcher		
3	**Rent - Happy Seeder**	small to medium scale	Combine Harvester with Super SMS	Fixed bonus	High HP tractor required
			Happy Seeder		
4	**Rent - Rotavator + other Machinery**	small to medium scale	Combine Harvester with Super SMS	Fixed bonus	High HP tractor required
			Rotavator		
			Reversible Plough, Straw Chopper or Mulcher		
5	**Rent - Baler**	small, medium or large scale	Combine Harvester with Super SMS	Fixed bonus	High HP tractor required
			Baler		Value for residue sold received by farmers
6	**Burn - full or partial**	small, medium or large scale	Combine Harvester without Super SMS		No special considerations
			Rotavator (rent)		

Table 4.2.1 Six rice residue management scenarios considered for analysis

4.2.1 Purchase – Happy Seeder

For the purchase of Happy Seeder, a farm size of 15 acres is assumed (small scale farmers are unlikely to afford the purchase of machinery), and the calculations are for an individual farmer who is the sole purchaser. The cost of purchase of a Combine Harvester with Super SMS is included in the capital cost. The lifetime of the Happy Seeder is assumed to be 10 years, and the costs include two rounds of repair. Individual farmers as assumed to receive a 50% subsidy on the initial cost of machinery from the government after one year of purchase, while farmer groups receive an 80% subsidy for the same. It is assumed that a high horsepower (HP) tractor to operate a Happy Seeder is readily available to those in either case.

4.2.2 Purchase – Rotavator + Other Machinery

A rotavator is device that uses rotating blades to turn the soil. It is used with other Machinery that uses includes any combination of Reversible Plough, Mulcher or Reaper for in-situ incorporation of rice residue. The cost of purchase of a Combine Harvester with Super SMS is included in the capital cost as it improves the efficiency of in-situ incorporation. 14 of the 40 farmers interviewed use Rotavator in combination with one of the other devices to incorporate residue and sow the next wheat crop. Here too, a farm size of 15 acre the lifetime for all machinery is also assumed at 10 years and repair costs have been accounted for twice during this lifetime. Smaller Rotavators that run on tractors of about 40-50 HP tractor are easily available to farmers. However, machines such as the Reversible Plough, might require tractors with higher horsepower. The calculations assume that an individual farmer purchases the machinery for which they receive 50% subsidy on capital costs of machinery (Reversible Plough, Mulcher or Reaper) from the government, while farmer groups receive 80% subsidy. No government subsidy is provided for a Rotavator.

4.2.3 Rent – Happy Seeder

The rental cost includes cost of renting a (i) a Combine Harvester with a Super SMS and (ii) a Happy Seeder. Renting agricultural machinery is assumed to be undertaken by small and medium scale farmers. Farmers can rent devices from farmer cooperatives, or large-scale farmers in the village that own the device. The option of renting a Happy Seeder requires a high HP tractor to operate.

4.2.4 Rent – Rotavator + other Machinery

This option includes the cost of renting (i) a Combine Harvester with Super SMS, (ii) a Rotavator and (iii) Other Machinery (a Reversible Plough or Straw Chopper & Mulcher). Renting agricultural machinery is undertaken by small-medium scale farmers. Farmers can rent required machinery from farmer societies and cooperatives, or large-scale farmers in the village owning the machinery. Smaller Rotavators that run on tractors of about 40-50 HP tractor are easily available to farmers. However, machines such as Reversible Plough, might require higher HP tractors, this option thus depends on the availability of machines and high horsepower tractors for rent during the short harvest period.

4.2.5 Rent - Baler

The rental cost includes cost of renting a (i) Combine Harvester with Super SMS and (ii) a Baler with a high horsepower tractor. Renting agricultural machinery is undertaken by small-medium scale farmers. Farmers can purchase required machinery from farmer societies and cooperatives, or large-scale farmers in the village owning the machinery. The cost calculation includes the value of the residue as the amount received by a farmer, per quintal of residue sold. The option renting a Baler to manage residue, while economically feasible, depends on the availability of a Baler and a high horsepower tractor during the short harvest period. This option is also only feasible for farms located close to a factory that has the capacity to take the amount of residue.

4.2.6 Burn – full or partial

Cost for managing residue by either partially or completely burning it on the field includes cost of renting a Combine Harvester without Super SMS and renting a Rotavator. There is no requirement for a high horsepower tractor or to rent a Super SMS for this alternative.

4.3 Cost Analysis: Residue management and field preparation

All primary data for cost analysis is gathered from 40 semi-structured interviews with rice farmers and secondary data was extracted from Shyamsundar et al., (2019) where primary data was missing or insufficient.

Figure 4.3.1 shows the annualised NPV (lifetime of 10 years) of cost of field preparation using the six common residue management practices, with and without government incentives. The government incentives include 50% subsidy on purchase of agricultural machinery, except Rotavator, fixed bonus incentive, and regulated sum of money received by farmers giving away residue when using Baler. The cost calculation for without government incentives (w/o gov. incentive), do not include these monetary benefits to farmers when undertaking active residue management. Figure 4.3.2 through figure 4.3.6 represent a breakdown of the field preparation expenses through the five active residue management practices considered. The capital costs for the machinery purchase option correspond to full machinery cost, before government subsidy. Figure 4.3.7 shows the breakdown of field preparation costs when practicing status quo of residue burn. There are no government incentives associated with residue burning.

Figure 4.3.8 shows results from sensitivity analysis of resulting total costs for each residue management practice (with government incentive) due to variation in data. The figure shows total minimum, mean, and maximum costs for each of the six residue management practice.

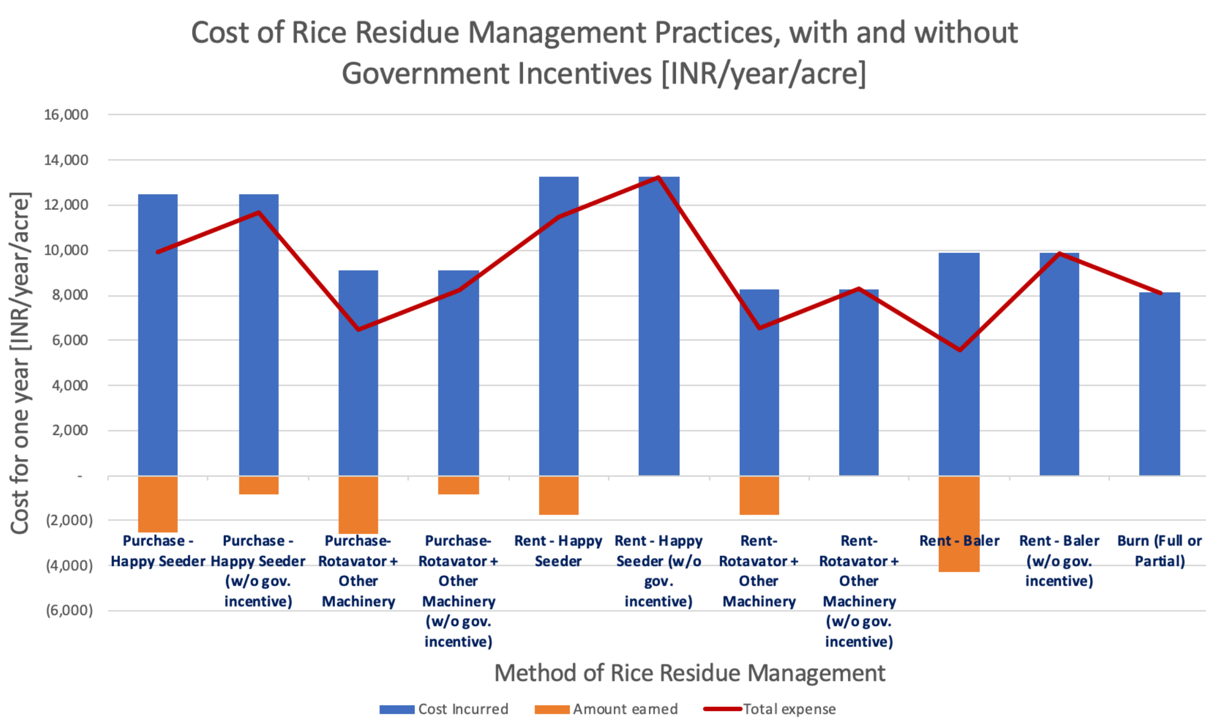


Figure 4.3.1 Cost of field preparation with different rice residue management practices with and without government incentives

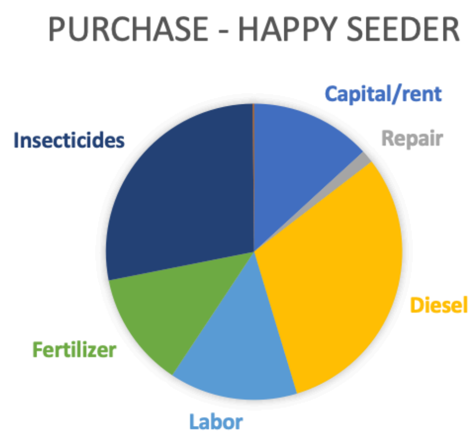


Figure 4.3.2 Breakdown of capital and operation costs of field preparation when purchasing Happy Seeder

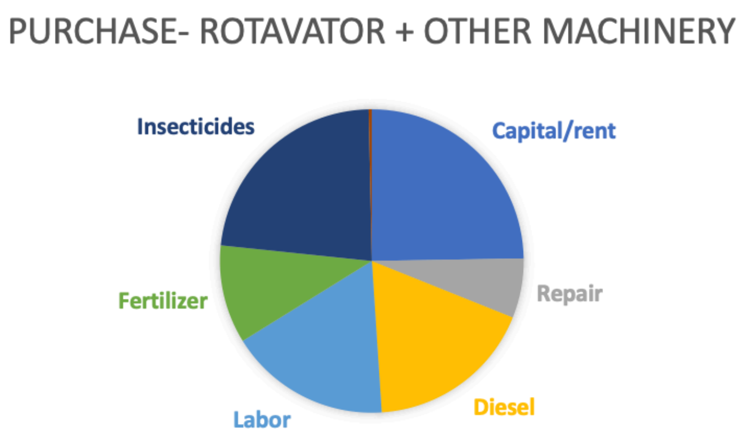


Figure 4.3.3 Breakdown of capital and operation costs of field preparation when purchasing Rotavator + other machinery

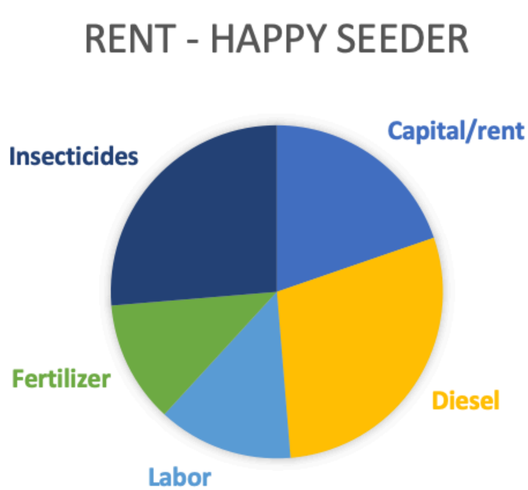


Figure 4.3.4 Breakdown of capital and operation costs of field preparation when renting Happy Seeder

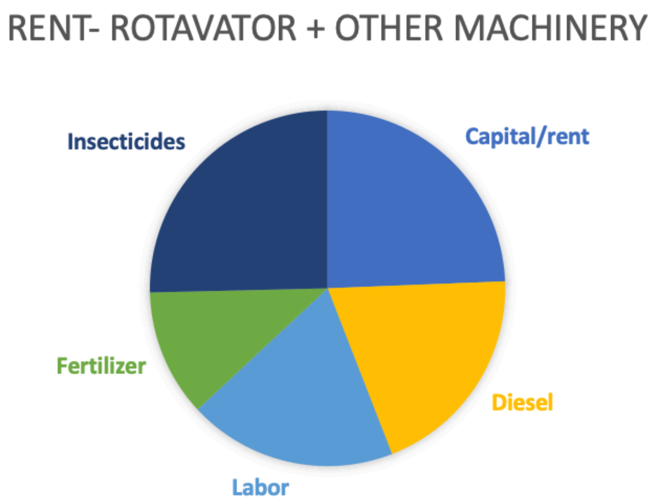


Figure 4.3.5 Breakdown of capital and operation costs of field preparation when renting Rotavator + other machinery

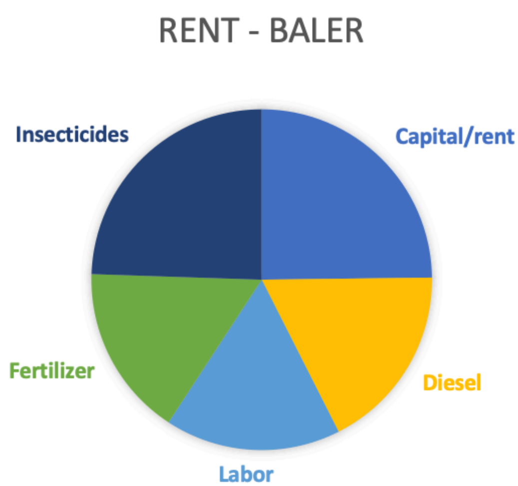


Figure 4.3.6 Breakdown of capital and operation costs of field preparation when renting Baler

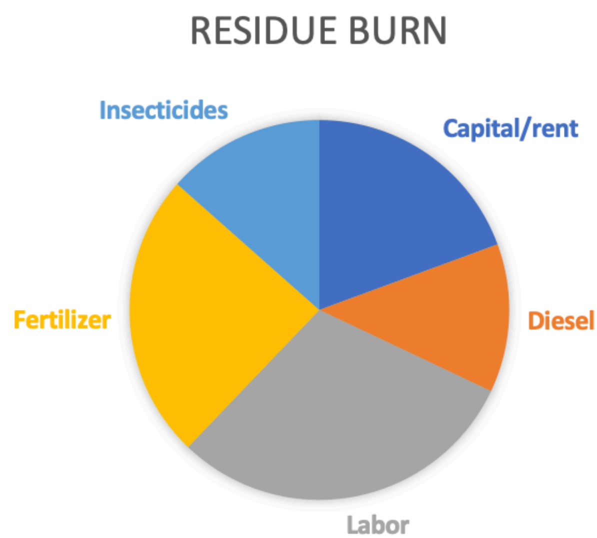


Figure 4.3.7 Breakdown of capital and operation costs of field preparation with residue burn practice

As seen figure 4.3.1, barring the option of purchasing or renting a Happy Seeder, the cost of all active management practices is comparable or less than the status quo (burning). A cost breakdown reveals also reveals the following:

- **Capital Costs**: Figure 4.3.2 through figure 4.3.7 show that capital costs make up a large part of the expense bore by the farmer for each residue management practice. Annualized capital costs of machinery purchase range are about 1650 INR/yr/acre for Happy Seeder and 2254 INR/yr/acre for Rotavator + other machinery before government subsidy. While annualized capital cost for machinery rent range from 2615 INR/yr/acre for Happy Seeder to about 1570 INR/yr/acre to rent Rotavator for status quo of full or partial residue burn. Given the short time duration to manage rice residue, only a Rotavator is not sufficient for in-situ incorporation. Farmers would also be required to purchase and use a Reversible Plough or Mulcher along with Rotavator. Further, there is no government subsidy on Rotavator. This results in high capital cost for purchase of Rotavator + Other Machinery. The provided costs for machinery purchase are for individual farmers receiving 50%

subsidy from the government. However, farmer groups of 8 farmers are eligible to receive 80% government subsidy on purchase of machinery with shared ownership. This can help improve access through purchase of machinery by reducing the capital cost. Farmer groups can also choose to rent machines to other farmers, provided with extra time in the harvest season, thus improving the machinery rental market in villages.

- **Fuel and Diesel Costs**: Annualized fuel costs range from 3845 INR/yr/acre to 1025 INR/yr/acre. They are highest when using Happy Seeder, followed by Baler and Rotavator + Other Machinery as these machines requires the use high HP tractor. To use a Rotavator in combination with other machines such as a reversible plough or mulcher to manage rice residue in-situ, the tractor needs to be operated on the field several times which increases the diesel consumption. Whereas diesel costs are lowest for full or partial burn as this alternative requires the least field preparation.

- **Costs of farm input**: Farmers reported that fertilizer costs are lowest for in-situ incorporation, i.e. through purchase or rent of Rotavator + Other Machinery. This is consistent with the idea that in-situ incorporation rice residue balances the soil nitrogen content and adds organic carbon and other nutrients back into the soil (P. Kumar et al., 2015). Burning residue on the field kills both the harmful as well as friendly insects, does not allow for nutrients to return to the soil and causes deterioration of soil properties (P. K. Gupta et al., 2004). This increases the amount of fertilizer required for consecutive crops. Costs of insecticide use in the following season, though strictly not field preparation costs, were also estimated, because different management options result in different levels of pest presence. Both farmers and experts highlighted the increase in insect and pest attacks in the winter wheat crop after using Happy Seeder to sow wheat. This is reflected in the high insecticide cost for purchase and rent of Happy Seeder.

- **Government Subsidies:** Purchase of machinery by individual farmers is calculated at 50% subsidy, as provided by the government. A subsidy of INR 75,600 for Happy Seeder and almost INR 77,700 for Other Machines provided in the form of reimbursement is accounted for at the end of first year. In annualized NPV terms these subsidies offset annual costs of about 48.4% for Happy Seeder and 36% for Rotavator + other machines. The analysis also include a bonus of INR 100/quintal (INR 2500/acre) mandated by the Supreme Court to mitigate air pollution by AWB in 2019 for clean residue management practices, i.e. for purchase of Happy Seeder and Rotavator + Other Machines, and rent of Happy Seeder, Rotavator + Other Machines, and Baler. This bonus incentive does not apply for residue burn alternative. In annualized terms, the average value of the bonus (assuming an average yield of 15 acre) offset 17.6% and 15% from costs for purchase and rent of Happy Seeder respectively, ~27% and from costs for both purchase and rent of Rotavator + other machines, and 31% for costs for rent of Baler. The cost analysis also includes a regulated amount of INR 2500/acre received by farmers using Balers when selling the residue for ex-situ management. This received value to the rice residue offsets 45% of annual cost of residue management when using a Baler.

Figure 4.3.1 shows that the total cost of residue management for each active management practice is considerably higher without government incentives compared to total costs with government incentives. In order to manage rice residue by full or partial burn of residue, the locus of control lies with the farmer and there are few machinery access and coordination considerations to be made.

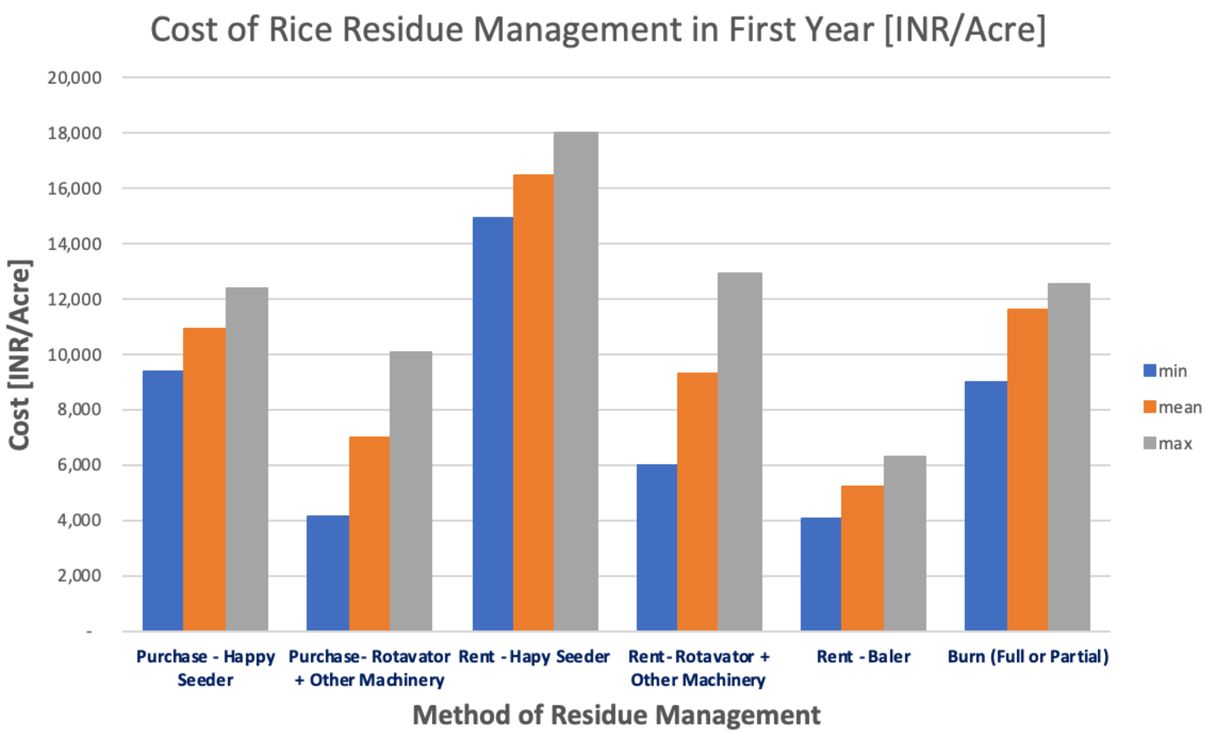


Figure 4.3.8 Variation in cost of residue management at end of 1st year, with government incentive

As presented in Figure 4.3.8, the variation in the cost of residue management for both purchase and rent of Rotavator + Other Machinery is large. This variation is due to the variation of machines available to the farmer under 'Other Machines' and the combination of which the farmer chooses to apply along with Rotavator. Other Machine includes Reversible Plough, Straw Chopper and Mulcher.

Summary of cost analysis

1. Government incentives of subsidy on machinery and fixed bonus are required to make active management alternatives less expensive than residue burn. Assuming farmers

receive government subsidy on machinery on time, all active management alternatives except rent and purchase of Happy Seeder (rent and purchase of Rotavator + other machinery and rent of Baler) are less expensive than residue burn.

2. Fixed bonus incentive can also play an important role in reducing the cost of active management (offsetting 15% to 31% costs for rent of Happy Seeder and Baler respectively) and providing farmers with a monetary incentive to switch away from status quo of residue burn.
3. Ex-situ residue management with the help of Balers can be cost effective for farmers, given government incentives and regulated amount received by farmers when selling the residue to factories and power-plants. However, the greater cost of ex-situ management falls on the government and the private sector to establish infrastructure and industry that can make use of the large amount of residue generated in Punjab.
4. Through our analysis, we find that the costs of active residue management, are often more cost effective than status quo of residue burn, there are various reasons for the insufficient adoption of active residue management practices. These include, inter alia, farmer's capacity to purchase or rent high HP tractor, access to agricultural machinery, government subsidy, perceptions of pest infestation and soil conditions post residue management, and regulations incentivising farmers to stop burning residue play an important role in the adoption of any residue management practice. These are discussed in chapter 5.

Our cost findings differ a bit from those of Shyamsundar et al. (2019) especially with respect to Happy Seeder, which their analysis finds to be the most cost-effective. These differences emerge from the choice of variables used, as well the specific details of cost assumptions. Their work models net profits for both cropping seasons, as opposed to costs of preparation modeled here.

When we compare the relative costs of field preparation this study to those from Shyamsundar et al. (2019), we find that.

1. Overall differences in cost of field preparation costs. The cost of field preparation according to this thesis is 14% lower for Purchase of Happy Seeder, 57% lower for Rotavator + other machinery, 53% lower for Baler and 36% lower for burn residue management method as compared to Shyamsundar et al. (2019). The higher costs for Shyamsundar et al. (2019) can be attributed primarily to inclusion of irrigation and harvest operation costs.
2. Subcategories included are different. The field preparation costs Shyamsundar et al. (2019) include are seed, irrigation pump, fertilizer, pesticide, rodent control, harvesting operations, and labor. This thesis takes into account diesel, labor, fertilizer and insecticide costs for field preparation, along with addition costs of harvesting rice residue with a Super SMS attached on the Combine Harvester and machinery repair costs for purchase alternatives. These differences in subcategories for cost calculation explain the differences in final costs for residue management practices between Shyamsundar et al. (2019) and this thesis.

An analysis comparing the methodology and analysis considerations of the two studies will be needed to compare the findings.

Shyamsundar et al. (2019) note the importance of government subsidies in scaling up active management technologies and making them more accessible, though their analysis does not account for subsidies. This thesis reiterates the importance by comparing the cost of residue management without the presence of government incentives (subsidy on machinery, fixed bonus and regulated residue purchase cost) to the cost of residue management with government incentives. The results show that the costs for active management of residue without government incentives are significantly greater than that with government incentives. It is thus important to understand the specific role of each government incentive, how it encourages the adoption of active management practices, and their shortcomings. In addition to a cost analysis, in chapter 5, this thesis goes to understand farmers' perspectives on the government incentives currently available in theory and the challenges that they face when accessing them in practice. Interviews with key experts also provide insights into other policy solutions such as better ex-situ residue management, cultivating short-duration rice variety and crop diversification aimed at addressing food-water-energy nexus concerns, stressing the need to address depleting groundwater resources in Punjab while tackling air pollution due to AWB.

Chapter 5: Government Incentives – Farmer and Expert Perspectives

There are various policy solutions being introduced by the Government of India, with the help of state governments, in order to contain agricultural waste burning post rice harvest season. While the analysis of field preparation costs reveals the putative importance of these subsidies for decision-making on residue management, farmer interviews reveal several ambiguities and challenges. Here we highlight the famers' perspectives on current government incentives including subsidy on agricultural machinery and fixed bonus. Farmers express the role of government policies in switching away from status quo of residue burning, and how they may fail to meet their desired goals.

Subsidy for Agricultural Machinery: Residue management technologies such has Super SMS, Happy Seeder, Super Seeder, Reversible Plough, Zero-Till Drill and Mulcher are eligible for subsidies that involve 50% cost rebate on capital cost for individual farmers and 80% for farmer groups with shared ownership. In our interviews, farmers have highlighted many cost and access problems with government subsidy on agricultural machinery. Some farmers claimed that presence of government subsidy on machinery has inflated its market price, i.e., the subsidy is simply being passed on to the retailers and suppliers of farm machinery, and not benefitting the presumptive beneficiaries. In addition, farmers are required to purchase machinery at cost from a licenced manufacturer and the subsidy is then received in the form of reimbursement between six months to two years later. This can add to the carrying costs of a farm, and to the financial burden. As noted by one farmer, "Government should pay subsidy on agricultural machines directly to farmers. It is wrong that they give it to the companies." In addition, experts have also raised concerns of subsidy fraud, questioning if it the government subsidy on machinery is ultimately reaching its intended beneficiary.

Small scale farmers also noted that they cannot purchase expensive agricultural machines and thus do not receive the benefit of the government subsidy; many small to medium scale farmers claim that the subsidy only benefits manufacturing companies and wealthy farmers, and not to small farmers. As one small farmer noted: “We have only heard about it, never gotten it. Even if farmers get it, those who have influence in the government, they take it. Common farmer does not get it.” Another concern is that the subsidy is applied unevenly. For instance, the Rotavator, a popular plowing device, and when combined with other machines, a potentially important means of residue management is not subsidized.

Fixed Bonus: In addition to the capital subsidies on machinery, and as noted in the cost analysis, the Supreme Court of India required governments to provide an INR 100 per quintal (100 kg) of yield as a bonus to small scale farmers who own 5 acres or less of land, and who have not participated in agricultural waste burning. This reward-based incentive is meant to financially assist small scale farmers to cover expenses related to active management. In the interviews, farmers expressed that provision of fixed bonus incentive can be effective in offsetting the extra cost of active residue management compared to status quo of residue burn. As one farmer stated: “If they give INR 2500/acre or INR 100/quintal, then no farmer will set the residue on fire.” There exist, however, constraints with access to the fixed bonus incentive. Farmers stressed that the fixed bonus should be provided to all farmers, irrespective of farm size, to manage rice residue sustainably. As noted by one farmer: “Yes, everyone should get the INR 100/quintal fixed bonus.

Irrespective of whether he is a large-scale farmer or small scale. The small farmer is definitely going to set the residue on fire because he does not have the equipment. The larger farmer who does not burn the residue, does not get anything." Some experts however believe that providing a fixed bonus of INR 100 per quintal will not solve the problem of AWB as this continues to put the onus of sustainable residue management on farmers without providing them with the proper means and infrastructure for it.

There has been no indication for the fixed bonus to be continued for the year 2020 and later. The uncertainly in the availability of the fixed bonus government incentive for consecutive years makes it difficult for farmers to plan for residue management in advance.

Due to insufficient monitoring of field fires, farmers undertaking agricultural waste burning were able to fill out forms to receive the fixed bonus incentive as well.

5.1 Other Policy Solutions

While the previous analyses focused on the management of residue on the field, there are other ways by which burning of rice stubble can be avoided. This might be through: (i) ex-situ management of residue, (ii) by reducing the amount of stubble left in the field post-harvest or (iii) by cropping crops that do not leave extensive stubble on the ground.

5.1.1 Ex-situ Rice Residue Management

Ex-situ residue management after collecting residue from the field with Balers, was considered one of the most preferred residue management practices by farmers. Farmers see a potential value in selling rice residue to power plants and factories, both in terms of personal monetary benefit and conversion of residue from waste to raw material. Farmers understand that rice residue can be used to generate electricity, produce biogas and fertilizers in factories, and in this way provide employment and increased income for the village. As one farmer stated: “Our people can also work there, and they will get employment. The village will also get the electricity generated from the residue.” Farmers however recognise that it is not in the government’s capacity to facilitate the collection of residues from all the fields around Punjab. The short time window available for rice harvest and field preparation makes the task further challenging. Interviewed farmers suggest local residue collection centres be set up by the government in each village during the time of harvest where farmers can deposit their collected residue in time. A major access constraint for ex-situ residue management is the access to Baler machines in the short time window and a heavy tractor required to operate it.

Ex-situ residue management can be an important mitigation measure, if rice production in Punjab is to continue, converting a waste product currently causing damage to the environment into a potentially valuable raw material. Interviewed experts highlighted many applications of rice residue, such as natural gas and electricity generation, and as raw material for paper and building board. They stressed on the expansion of infrastructure to improve access to Balers and residue collection factories for farmers.

5.1.2 Short Duration Rice Variety

Currently the most popular rice variety in Punjab is Pusa 44, which is a long duration hybrid variety that takes 130 days to mature after a 30-day nursery transplantation period. Other short duration rice varieties introduced by the Punjab Agricultural University include the PR 126, PR 124, PR 127, PR 121, and PR 122 that take 93, 105, 107, 110, and 117 days respectively to mature once transplanted to the field (Ministry of Agriculture and Farmers Welfare, 2019). The Pusa 44 variety has the highest yield among available varieties of rice (Ministry of Agriculture and Farmers

Welfare & Department of Agriculture, Cooperation & Farmers Welfare, 2019) making it an attractive variety to cultivate. In an effort to reduce the area under Pusa 44, Government of India's Ministry of Agriculture has directed the Food Corporation of India (FCI) and other state procurement agencies to not procure this variety in Punjab (Nibber, 2020). Growing short duration rice variety provides farmers with a longer time between rice harvesting and sowing of wheat crop for the Rabi season, during which (if provided with reliable electricity) they can let the rice residue anaerobically decompose in water. This makes in-situ incorporation more feasible. Further, agricultural waste burning of short duration variety rice takes place in pre-winter conditions and thus have reduced impact on ambient air pollution in the Indo-Gangetic Plain.

Both farmers and experts state that by encouraging farmers to cultivate Basmati, a different variety of rice, can also help reduce AWB. The Basmati rice straw has lower silica content and so can be used as animal fodder (Lohan et al., 2018). The Basmati straw is also softer making it easier to incorporate into the soil. Farmers also explained that Basmati variety of rice is harvested manually, leaving behind less amounts of residue on the field. Interviewed farmers growing Basmati on part of their land did not burn its residue but also found it a financial risk to grow Basmati in majority or all of their fields due to lack of government MSP on the crop.

5.1.3 Crop Diversification and Minimum Support Price (MSP)

Almost 90% of the interviewed farmers expressed interest in switching away from cultivating rice, if provided with a reliable market for other crops. Crops such as such as maize, vegetables, American cotton, and pulses were some of the emergent alternatives to cultivating rice in the Kharif season from the interviews. Depletion of ground water was stated as a major concern amongst farmers in Punjab and is thus a motivator for crop diversification. As noted by one farmer:

“If the government gives INR 200/quintal [fixed bonus], that will only help with the rice residue, it will not help with the water consumption. Water consumption will remain the same only. If the government wants to save water or the environment, then it should support other crops and after that give money.” An expert further stated: “But the real problem is the spread of paddy cultivation. So that should be top priority. If you only focus on crop burning, what will happen to the water table?” However, farmers expressed that the biggest challenge to crop diversification is the lack of guaranteed market for other crops, increasing their risk of cultivation non-paddy crops. Due to lack of mechanisation of non-paddy crops, cultivating vegetables is more labor-intensive. The rising cost of agricultural labor in Punjab can increase cost of cultivation for farmers. As stated by one farmer: “If proper rates [for other crops] are fixed, then no farmer will look at paddy.” Marginal and small-scale farmers are unable to take the financial risk of cultivating other crops such as maize, vegetables, and pulses that are sold in the open market without a guaranteed buyer providing a fixed price that is agreed upon prior to the commencement of the season.

Rice is not the staple food in Punjab. The Food Corporation of India (FCI) buys rice grains from farmers in Punjab at MSP to meet India’s national food security demands. Punjab contributes to 24.20% of India’s central rice pool (Grover et al., 2016). However, the rice-wheat mono-cropping cycle has come to a great cost for farmers in Punjab. The provision of rice procurement at MSP and guaranteed monitory return at the end of the Kharif season is the main reason farmers continue to grow rice despite contrary recommendations from scientists and policy experts, and depletion of groundwater resources. Interviewed experts stressed in importance of crop diversification in Punjab and recommended phasing out rice cultivation in parts of the state while simultaneously setting up markets for other less water intensive crops.

There are two key factors to keep in mind when recommending a shift away from rice cultivation and crop diversification in Punjab. Since Punjab is a major rice contributor to the central rice pool for National Food Security, experts have cautioned that it is important to slowly phase out rice cultivation in Punjab ensuring other rice producing states can fulfill India's rice demand. States of West Bengal, Uttar Pradesh, Andhra Pradesh, Bihar and Tamil Nadu along with Punjab are some of the top rice producers in India (National Horticulture Board, 2018). The second challenge is reducing the reliance on MSP to produce crops and create a competitive market. It is however important to protect the interests of marginalised and small-scale farmers to prevent them from doing into a downward financial spiral. State regulated contract farming could potentially play an important role in helping small and medium scale farmers to adopt other crop varieties (SINGH, 2012).

Chapter 6: Conclusion

The expansion of rice production in Punjab through guaranteed Minimum Support Price (MSP) and free electricity and water, mechanisation of rice production, increased cost of labor, and the Water Law in 2009 have collectively led to increased production of rice residue and open Agricultural Waste Burning (AWB) in Punjab. The rapid growth of rice cultivation in Punjab and availability of free electricity and water, has led to a depletion of groundwater level in Punjab, which together with AWB, should be a major point of concern for Indian policymakers. In order to reduce the amount of area under rice cultivation in Punjab experts and farmers pointed towards crop diversification as an important solution. About 90% of interviewed farmers expressed interest in growing other crops including maize, vegetables, and American cotton in order to stop cultivating rice to protect local groundwater resources – a shift that would mitigate groundwater depletion, while addressing the AWB problem, and would require persuading farmers away from planting rice. This might be enabled by the guaranteed procurement of other crops at MSP by the government and providing farmers with financial security when cultivating crops other than rice and wheat.

The three important solutions to AWB include: in-situ residue incorporation, ex-situ residue management and crop diversification. The cost analysis in this study shows that given the government incentives of subsidy on agricultural machines, fixed bonus, and a price incentive to sell the residue to factories, the cost of active rice residue management can be comparable with the status quo of residue burn. Active management of rice residue by renting or purchasing Rotavator in combination with other machines such as Reversible Plough, Straw chopper and Mulcher, and renting a Baler can often be more economical than burning residue. The Ministry of New and

Renewable Energy's (MNRE) biomass gasifier program encourages biomass gasifier based power plants that can have applications for agricultural biomass for electricity generation (Kumar, 2017). Selling rice residue to be used as raw material in various applications including power generation, manure production, paper mills, and making building elements, can provide additional income to farmers and incentivise them to sustainably manage rice residue. Yet, there remain a number of barriers related to cost, access and availability of these machines than can make it prohibitively expensive for small farmers to move away from the AWB status quo.

While semi-structured interviews provided a nuanced assessment of the challenges with adoption of active management practices and access to government incentives and explored farmers' concerns of groundwater depletion, the method has its shortcomings. A key limitation of this research is the small sample size for farmer interviews, particularly from primarily three districts in Punjab. Thus, while providing valuable insights into residue management practices and the associated costs for farmers, the study results are limited by geography. A survey covering the rice producing districts of Punjab and a more comprehensive inclusion of stakeholders would be of great benefit to a future study on AWB and the agrarian environmental crisis in Punjab.

Rice farmers are an important stakeholder in the solution landscape of the food-water-air nexus in India's granary. This study highlights their residue management decision making process and feasibility of policies aimed at sustainable residue management. However, solutions to agrarian problems that underlie AWB will need to do more than examine residue management. The continuing depletion of groundwater implies that the cultivation of rice in North-western India will need to be discontinued. Depleting ground water resources in Punjab will also have dire consequences for India's food security. Given the scale of the problem and the health of half a billion people in the Indo-Gangetic Plain at stake, the food-water-energy nexus that shapes AWB needs to be addressed immediately by its many stakeholders including farmers, scientists, and policy makers.

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Appendices

Appendix A Semi- structured Interview Questionnaire

Following is the semi-structured interview questionnaire for farmers and experts in Punjab. This was used as primary data collection for the study. The questionnaire for farmers is translated into English form Hindi by the student.

A.1 Farmer Interviews

This section presents the English translation of semi-structured interview questionnaire for farmers in Punjab.

The interview questionnaire begins here.

Demographic Questions:

Name:

Sector and Village:

# of years participant has been farming for:

Q. What crops do you grow on your farm and how many hectares of each crop?

Q. What variety of rice did you cultivate this year?

Q. How much money did you spend for rice cultivation including fertilizers, insecticides, seeds, labor, diesel, and irrigation?

Q. What methods do you use to harvest the rice crop?

Q. How familiar are you with the following:

- Super SMS, Happy Seeder, Rotavator, Using rice residue as fodder, Collecting rice residue for ex-situ management

Q. How do you manage the rice residue, specifically what residue management method did you use this October-November?

Q. According to you what would be the most preferred way to get rid of rice residue?

Q. Removing cost, labor and access constraints, what would be the most preferred way to get rid of rice residue?

Q. [If participant uses agricultural machinery] Do you rent the machine or have you bought it?

- How much do you rent it from?
- Where do you rent it from?

Q. Did you receive any training to use these machines?

- What kind of training did you receive?
- In your opinion is that training sufficient?

Q. Have you recently switched your residue management method or have you been managing rice residue in this manner since many years?

Q. Do you belong to any farmers' co-operative or farmer union?

- What information/help do they provide?

Q. In order for farmers to stop burning rice residue, what form of assistance from the government would you prefer?

- Full subsidy on agricultural machinery or fixed bonus incentive (like the Supreme Court asked Punjab government to give farmers this year for not burning residue)?
- Full subsidy on agricultural machinery or a fixed procurement price (MSP) on crops other than rice?
- Fixed bonus incentive or fixed procurement price (MSP) on crops other than rice?
- Fixed bonus incentive or help with collecting and transporting residue?
- Full subsidy on agricultural machinery or help with collecting and transporting residue?

- Help with collecting and transporting residue or fixed procurement price (MSP) on crops other than rice?

Q. Do you agree or disagree with the following regarding open burning of rice residue:

- It results in poor air quality in the village
- It improves the quality of the soil
- It reduces the yield of the next crop
- It reduced the need for fertilizers
- It increases water consumption for irrigation
- It results in respiratory and health issues

Q. Have you considered switching to cultivating crops other than rice in the Kharif season?

- Which crops would you like to grow?
- What are the reasons and challenges due to which you have not been able to grow those crops?

Q. How much monitory compensation from the government do you think is appropriate to help farmers shift from burning rice residue to managing it sustainably?

A.2 Expert Interviews

This section presents the questionnaire for semi-structured interviews with agronomic experts. This is a general interview. Some questioned were tweaked to make them more relevant to the participant's area of expertise.

The interview questionnaire begins here.

Q. What role did the Punjab preservation of subsoil water act of 2009 play in both water conservation and Agricultural Waste Burning (AWB)?

Q. What are the other key reasons that form the problem landscape of open residue burning?

Q. Has AWB always been a problem that is only recently being highlighted in the news, or is it in fact increasing in these past 5-10 years?

Q. Would you describe AWB as a behavioral issue or an economic issue?

Q. What measures do you think would be most effective to help farmers switch to sustainable residue management practices: increasing awareness among farmers, monitory incentives, training, etc.

Q. Do you think that penalising farmers that burn residue and rewarding farmers who do not burn the residue will show positive results?

Q. Talking about government subsidies on agricultural machinery, do you think that it is being implemented well and serving its purpose?

Q. What do you think about Happy Seeder?

Do you think that it is a potential solution to AWB?

Q. Can you please talk a little about crop diversification and shifting away from rice-wheat cropping cycle?

Is Minimum Support Price (MSP) a barrier? What should the government's strategy for this be?

Q. Who do you think should bear the larger blunt of the responsibility to reduce AWB? Central government, Punjab state government, Delhi state government or farmers?

Q. What steps should the Central government and Punjab state government take throughout the year to reduce AWB next year?

Q. According to you what is the scope for ex-situ residue management of rice residue?

Appendix B Semi-structured Interview Demographic

This section shows the demographic data of all semi-structured interviews conducted with farmers for the study.

B.1 Farmer Interviews

District	Village	Farmer code	Farm size	District	Village	Farmer code	Farm size
Ludhiana	Killa Raipur	1	45	Patiala	Rongla	25	7
		2	125			26	10
		3	35			27	-
		4	90			31	3
		6	25			32	4
	Sahnewal	7	20			33	5
	Dhaka	12	35			34	labor
		13	27.5		Samana	36	25
		14	5			37	15
	Ludhiana	17	7			38	
		18	20			39	6
Gurdaspur	Sohian	16	25			40	10
	Hari ke kalam	19	5			42	20
		20	60			35	
		8	25	Bhatinda	Rampura Phul	41	47
		21	4			43	6
		22	6			44	13
		23	30			45	35
						46	11
						47	20.5
						48	10
						49	32

Table B.1.1 Farmer interviews demographic data

Appendix C Primary Data

This section presents all primary data regarding cost of rice cultivation for farmers in Punjab for using different active management of rice residue and burning residue on the field. The costs have been extracted from the semi-structured interviews conducted with farmers in Punjab.

Rotavator + Other Machines			# of farmers	15	
	Unit	**min**	**mean**	**max**	**# of Observation**
Rent	INR/acre	800	1137.5	1500	5
	INR/hr	100	100	100	2
Diesel	INR/acre	1400	2331.25	3500	10
Labor	INR/acre	1000	2243.75	3500	8
Fertilizer	INR/acre	1000	1000	1000	1
Insecticides	INR/acre	3000	3000	3000	1

Table C.2.1 Primary data for cost of rice cultivation using Rotavator + Other Machinery for residue management

Happy Seeder			# of farmers	3	
		min	**mean**	**max**	# of Observation
Rent	INR/acre	2000	2000	2000	1
Diesel	INR/acre	5500	5500	5500	1
Labor	INR/acre	2500	2500	2500	1
Fertilizer	INR/acre	2250	2250	2250	1
Insecticides	INR/acre	5000	5000	5000	1

Table C.2.2 Primary data for cost of rice cultivation using Happy Seeder for residue management

Baler			# of farmers	6	
		min	**mean**	**max**	# of Observation
Rent	INR/acre	1500	1,750	2000	4
Diesel	L/hr	11	11	11	1
Labor	INR/acre	2200	2350	2500	2
Fertilizer	INR/acre	5750	2300	2300	1

Insecticides	INR/acre	3450	3450	3450	1

Table C.2.3 Primary data for cost of rice cultivation using Baler for residue management

Burn (full or partial)			# of farmers	10	
		min	**mean**	**max**	# of Observation
Rent	INR/acre	1000	1100	1300	3
	INR/hr	100	100	100	1
Diesel	INR/acre	1000	1,467	2000	3
Labor	INR/acre	3000	3000	3000	1
Fertilizer	INR/acre	870	910	950	2
Insecticides/pesticides	INR/acre	5000	5000	5000	1

Table C.2.4 Primary data for cost of rice cultivation by burning residue on the field

Appendix D Primary + Secondary Data

This section provides a synthesis of both primary and secondary data on cost of rice cultivation when using different active residue management practices and burning residue on the field. Secondary data was extracted from Shyamsundar et al., (2019)

Rotavator + Other Machines		
Rent	1135.55162	INR/acre
Diesel	2331.25	INR/acre
Labor	2243.75	INR/acre
Fertilizer	1,366.40	INR/acre
Insecticides	3000	INR/acre

Table D.1 Final cost of rice cultivation using Rotavator + Other Machinery for residue management

Happy Seeder		
Rent	2000	INR/acre
Diesel	5500	INR/acre
Labor	2500	INR/acre
Fertilizer	2250	INR/acre
Insecticides	5000	INR/acre

Table D.2 Final cost of rice cultivation using Happy Seeder for residue management

Baler		
Rent	1,750	INR/acre
Diesel	-	
Labor	2350	INR/acre
Fertilizer	2300	INR/acre
Insecticides	3450	INR/acre

Table D.3 Final cost of rice cultivation using Baler for residue management

Burn (full or partial)		
Rent	1100	INR/acre
Diesel	1,467	INR/acre
Labor	3,490.99	INR/acre
Fertilizer	2,826.31	INR/acre
Insecticides	1,561.40	INR/acre

Table D.4 Final cost of rice cultivation by burning residue on the field

Appendix E Cost Analysis

This section presents the cost of residue management and rice cultivation using four active management methods: Purchase of Happy Seeder, Purchase of Rotavator + Other Machinery, Rent of Happy Seeder, Rent of Rotavator + Other Machinery, Rent of Baler; and full or partial burning of residue on the field. The cost analysis is carried out under three scenarios: cost of residue management cumulatively over 10 years with government incentive, cost of residue management cumulatively over 10 years without government incentive, and cost of residue management bore by the farmer in the first year. The tables are present the individual costs for capital/rent, government subsidy, repair, diesel, labor, fertilizer, insecticide, salvage, residue selling income, and fixed bonus prices. All costs presented are in INR/acre, unless mentioned otherwise. 55.6 INR = 1 CAD. The following assumptions have been made for the analysis:

Inflation	3.34%
Discount Rate	10%
Bank loan interest	7%
Capital cost down-payment	20%
Salvage	2%
Average farm size	15 acre

Table E.1 External assumptions for cost analysis

E.1 Cash Flow

Capital	Year 1	2	3	4	5	6	7	8	9	10	NPVs
3,509	$3,424	$3,424	$3,424	$3,424	$3,424						16,487
Subsidy	(8,773)										(7,976)
Repair				1,000			1,000				1,736
Diesel	5,500	5,687	5,880	6,080	6,287	6,501	6,722	6,950	7,187	7,431	38,449
Labor	2,500	2,585	2,673	2,764	2,858	2,955	3,055	3,159	3,267	3,378	17,477
Fertilizer	2,250	2,327	2,406	2,487	2,572	2,659	2,750	2,843	2,940	3,040	15,729
Insecticides	5,000	5,170	5,346	5,528	5,715	5,910	6,111	6,318	6,533	6,755	34,953
Salvage										(202)	(183)
Fixed Bonus	(2,500)	(2,584)	(2,670)	(2,759)	(2,851)	(2,946)	(3,045)	(3,146)	(3,252)	(3,360)	(17,436)
Total	7,400	16,609	17,058	18,524	18,005	15,079	16,593	16,125	16,675	17,042	99,235

E.1.1 Cash flow for Purchase – Happy Seeder

Capital	**Year 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	NPV
4,797	$4,679	$4,679	$4,679	$4,679	$4,679						22,535
Subsidy	(8,912)										(8,102)
Repair				3,333			3,333				5,785
Diesel	2,331	2,411	2,492	2,577	2,665	2,755	2,849	2,946	3,046	3,150	16,297
Labor	2,244	2,320	2,399	2,480	2,565	2,652	2,742	2,835	2,932	3,032	15,685
Fertilizer	1,366	1,413	1,461	1,511	1,562	1,615	1,670	1,727	1,785	1,846	9,552
Insecticides	3,000	3,102	3,207	3,317	3,429	3,546	3,666	3,791	3,920	4,053	20,972
Salvage										(336)	(305)
Fixed Bonus	-2500	(2,584)	(2,670)	(2,759)	(2,851)	(2,946)	(3,045)	(3,146)	(3,252)	(3,360)	(17,436)
Total	2,209	11,341	11,569	15,139	12,049	7,622	11,216	8,153	8,432	8,385	64,984

E.1.2 Cash flow for Purchase – Rotavator + Other Machinery

	Year 1	2	3	4	5	6	7	8	9	10	**NPVs**
Rent - Combine Harvester + Super SMS	1,750	1,808	1,869	1,931	1,996	2,062	2,131	2,203	2,276	2,352	12,205
Rent - Happy Seeder	2,000	2,067	2,136	2,207	2,281	2,357	2,436	2,517	2,601	2,688	13,949
Diesel	5,500	5,684	5,874	6,070	6,272	6,482	6,698	6,922	7,153	7,392	38,360
Labor	2,500	2,584	2,670	2,759	2,851	2,946	3,045	3,146	3,252	3,360	17,436
Fertilizer	2,250	2,325	2,403	2,483	2,566	2,652	2,740	2,832	2,926	3,024	15,693
Insecticide	5,000	5,167	5,340	5,518	5,702	5,893	6,089	6,293	6,503	6,720	34,873
Fixed Bonus	(2,500)	(2,584)	(2,670)	(2,759)	(2,851)	(2,946)	(3,045)	(3,146)	(3,252)	(3,360)	(17,436)
Total	16,500	17,051	17,621	18,209	18,817	19,446	20,095	20,766	21,460	22,177	115,079

E.1.3 Cash Flow for Rent – Happy Seeder

	Year 1	2	3	4	5	6	7	8	9	10	**NPVs**
Rent- Combine Harvester + Super SMS	1750	1,808	1,869	1,931	1,996	2,062	2,131	2,203	2,276	2,352	12,205
Rent- Rotavator + other machinery	1,136	1,174	1,214	1,255	1,298	1,342	1,388	1,435	1,484	1,534	7,938
Diesel	2,331	2,411	2,492	2,577	2,665	2,755	2,849	2,946	3,046	3,150	16,297
Labor	2,244	2,320	2,399	2,480	2,565	2,652	2,742	2,835	2,932	3,032	15,685
Fertilizer	1,366	1,413	1,461	1,511	1,562	1,615	1,670	1,727	1,785	1,846	9,552
Insecticide	3,000	3,102	3,207	3,317	3,429	3,546	3,666	3,791	3,920	4,053	20,972
Fixed Bonus	(2,500)	(2,584)	(2,671)	(2,762)	(2,856)	(2,953)	(3,054)	(3,157)	(3,265)	(3,376)	(17,468)
Total	9,327	9,645	9,971	10,309	10,659	11,020	11,393	11,779	12,179	12,591	65,182

E.1.4 Cash Flow for Rent – Rotavator + Other Machinery

	Year 1	2	3	4	5	6	7	8	9	10	**NPVs**
Rent- Combine Harvester + Super SMS	1750	1,808	1,869	1,931	1,996	2,062	2,131	2,203	2,276	2,352	12,205
Tractor											
Baler	1,750	1,810	1,871	1,935	2,000	2,068	2,139	2,211	2,287	2,364	12,234
Diesel	2,500	2,585	2,673	2,764	2,858	2,955	3,055	3,159	3,267	3,378	17,477
Labor	2,350	2,430	2,513	2,598	2,686	2,778	2,872	2,970	3,071	3,175	16,428
Fertilizer Insecticide	5,750	5,946	6,148	6,357	6,573	6,796	7,027	7,266	7,513	7,769	40,196
Residue Selling Price	(3,625)	(3,746)	(3,871)	(4,000)	(4,134)	(4,272)	(4,415)	(4,562)	(4,715)	(4,872)	(25,283)
Fixed Bonus	(2,500)	(2,584)	(2,670)	(2,759)	(2,851)	(2,946)	(3,045)	(3,146)	(3,252)	(3,360)	(17,436)
Total	7,975	8,249	8,532	8,825	9,128	9,441	9,765	10,100	10,447	10,806	55,821

E.1.5 Cash Flow form Rent - Baler

	Year 1	2	3	4	5	6	7	8	9	10	
Rent - Combine Harvester	1150	1,188	1,228	1,269	1,312	1,355	1,401	1,447	1,496	1,546	8,021
Rent - Rotavator	1,100	1,137	1,176	1,216	1,257	1,300	1,344	1,390	1,437	1,486	7,690
Diesel	1,467	1,517	1,568	1,621	1,677	1,734	1,792	1,853	1,916	1,982	10,253
Labor	3,491	3,610	3,732	3,859	3,991	4,126	4,267	4,412	4,562	4,717	24,404
Fertilizer	2,826	2,922	3,022	3,125	3,231	3,341	3,454	3,572	3,693	3,819	19,758
Insecticide	1,561	1,614	1,669	1,726	1,785	1,846	1,908	1,973	2,040	2,110	10,915
Total	11,595	11,989	12,396	12,817	13,252	13,701	14,166	14,647	15,144	15,658	81,041

E.1.6 Cash Flow for Residue Burn (full or partial)

E.2 Cost of residue management for farmers over 10 years with government incentive

This section presents the cost of residue management for the various active management practices and residue burn cumulatively over 10 years, with government incentive of fixed bonus, and an income received by farmers upon selling residue collected through Balers. The values presented are the net present values.

	Purchase - Happy Seeder	Purchase-Rotavator + Other Machinery	Rent - Happy Seeder	Rent-Rotavator + Other Machinery	Rent - Baler	Burn (Full or Partial)
Capital/rent	16,487	22,535	26,154	20,144	24,439	15,710
Subsidy	(7,976)	(8,102)	N/A	N/A	N/A	N/A
Repair	1,736	5,785	N/A	N/A	N/A	N/A
Diesel	38,449	16,297	38,360	16,297	17,477	10,253
Labor	17,477	15,685	17,436	15,685	16,428	24,404

Fertilizer/Urea	15,729	9,552	15,693	9,552	16,079	19,758
Spray (Insecticides)	34,953	20,972	34,873	20,972	24,118	10,915
Salvage	(183)	(305)	N/A	N/A	N/A	N/A
Residue Selling Price	N/A	N/A	N/A	N/A	(25,283)	N/A
Fixed Bonus	(17,436)	(17,436)	(17,436)	(17,468)	(17,436)	
Total	99,235	64,984	115,079	65,182	55,821	81,041

Table E.2.1 Cost of residue management over 10 years with government incentive and residue selling price

E.3 Cost of residue management for farmers over 10 years without government incentive

This section presents the cost of residue management for the various active management practices and residue burn cumulatively over 10 years, without government incentive of fixed bonus, and an income received by farmers upon selling residue collected through Balers. The values presented are the net present values.

	Purchase - Happy Seeder	Purchase- Rotavator + Other Machinery	Rent - Happy Seeder	Rent- Rotavator + Other Machinery	Rent - Baler	Burn (Full or Partial)
Capital/rent	16,487	22,535	26,154	20,144	24,439	15,710
Subsidy	(7,976)	(8,102)	N/A	N/A	N/A	N/A
Repair	1,736	5,785	N/A	N/A	N/A	N/A
Diesel	38,449	16,297	38,360	16,297	17,477	10,253
Labor	17,477	15,685	17,436	15,685	16,428	24,404
Fertilizer/Urea	15,729	9,552	15,693	9,552	16,079	19,758

Spray (Insecticides)	34,953	20,972	34,873	20,972	24,118	10,915
Salvage	(183)	(305)	N/A	N/A	N/A	N/A
Total	116,672	82,420	132,516	82,650	98,540	81,041

Table E.3.1 Cost of residue management over 10 years without government incentive and residue selling price

E.4 Cost of residue management for farmers for the 1st year government incentive

This section presents the cost of residue management for the various active management practices and residue burn for the 1st year, with government incentive of fixed bonus, and an income received by farmers upon selling residue collected through Balers.

	Purchase - Happy Seeder	Purchase- Rotavator + Other Machinery	Rent - Happy Seeder	Rent- Rotavator + Other Machinery	Rent - Baler	Burn (Full or Partial)
Capital/rent	6,933	9,476	3,750	2,886	3,500	2,250
Subsidy	(8,773)	(8,912)	N/A	N/A	N/A	N/A
Repair	N/A	N/A	N/A	N/A	N/A	N/A
Diesel	5,500	2,331	5,500	2,331	2,500	1,467
Labor	2,500	2,244	2,500	2,244	2,350	3,491
Fertilizer/Urea	2,250	1,366	2,250	1,366	2,300	2,826
Spray (Insecticides)	5,000	3,000	5,000	3,000	3,450	1,561
Salvage	N/A	N/A	N/A	N/A	N/A	N/A
Residue Selling Price	N/A	N/A	N/A	N/A	(3,625)	N/A
Fixed Bonus	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	N/A
Total	10,910	7,006	16,500	9,327	7,975	11,595

Table E.4.1 Cost of residue management for 1st year with government incentive and residue selling price

Appendix F Sensitivity analysis of cost for residue management for 1st year with government incentive

This section presents ranges for the data synthesized from both primary and secondary sources for the cost of residue management in the 1st year. Figure F.1 is a concluding table for total costs pertaining to the six residue management practices considered. Sections F.1 to F.6 present the breakdown of costs for each of these practices. All costs presented are in INR/acre, unless mentioned otherwise. 55.6 INR = 1 CAD.

	Total Cost		
	min	mean	max
Purchase - Happy Seeder	9,385	10,910	12,435
Purchase- Rotavator + Other Machinery	4,164	7,006	10,097
Rent - Hapy Seeder	14,975	16,500	18,025
Rent- Rotavator + Other Machinery	5,975	9,327	12,958
Rent - Baler	4,091	5,215	6,339
Burn (Full or Partial)	9,002	11,595	12,546

Table F.1 Range for total cost for considered residue management practices for 1st year, with government incentive

F.1 For purchase of Happy Seeder

	Purchase - Happy Seeder		
	min	mean	max
Capital/rent	6,933	6,933	6,933
Subsidy	(8,773)	(8,773)	(8,773)
Repair	N/A	N/A	N/A

Diesel	4,950	5,500	6,050
Labor	2,250	2,500	2,750
Fertilizer/Urea	2,025	2,250	2,475
Spray (Insecticides)	4,500	5,000	5,500
Residue Selling Price	N/A	N/A	N/A
Fixed Bonus	(2,500)	(2,500)	(2,500)
Total	9,385	10,910	12,435

Table F.1.1 Cost range for residue management through purchase of Happy Seeder for 1st year, with government incentive

F.2 For purchase of Rotavator + Other Machinery

	Purchase- Rotavator + Other Machinery		
	min	mean	max
Capital/rent	9,476	9,476	9,476
Subsidy	(8,912)	(8,912)	(8,912)
Repair	N/A	N/A	N/A
Diesel	1,400	2,331	3,500
Labor	1,000	2,244	3,500
Fertilizer/Urea	1,000	1,366	1,733
Spray (Insecticides)	2,700	3,000	3,300
Residue Selling Price	N/A	N/A	N/A
Fixed Bonus	(2,500)	(2,500)	(2,500)
Total	4,164	7,006	10,097

Table F.2.1 Cost range for residue management through purchase of Rotavator + Other Machinery for 1st year, with government incentive

F.3 For rent of Happy Seeder

	Rent - Happy Seeder		
	min	mean	max
Capital/rent	3,750	3,750	3,750
Subsidy	N/A	N/A	N/A
Repair	N/A	N/A	N/A
Diesel	4,950	5,500	6,050
Labor	2,250	2,500	2,750
Fertilizer/Urea	2,025	2,250	2,475
Spray (Insecticides)	4,500	5,000	5,500
Residue Selling Price	N/A	N/A	N/A
Fixed Bonus	(2,500)	(2,500)	(2,500)
Total	14,975	16,500	18,025

Table F.3.1 Cost range for residue management through rent of Happy Seeder for 1st year, with government incentive

F.4 For rent of Rotavator + Other Machinery

	Rent - Rotavator + Other Machinery		
	min	mean	max
Capital/rent	2,375	2,886	3,425
Subsidy	N/A	N/A	N/A
Repair	N/A	N/A	N/A
Diesel	1,400	2,331	3,500
Labor	1,000	2,244	3,500
Fertilizer/Urea	1,000	1,366	1,733
Spray (Insecticides)	2,700	3,000	3,300

Residue Selling Price	N/A	N/A	N/A
Fixed Bonus	(2,500)	(2,500)	(2,500)
Total	5,975	9,327	12,958

Table F.4.1 Cost range for residue management through rent of Rotavator + Other Machinery for 1st year, with government incentive

F.5 For rent of Baler

	Rent - Baler		
	min	mean	max
Capital/rent	3,075	3,500	3,925
Subsidy	N/A	N/A	N/A
Repair	N/A	N/A	N/A
Diesel	2,250	2,500	2,750
Labor	2,200	2,350	2,500
Fertilizer/Urea	828	920	1,012
Spray (Insecticides)	1,863	2,070	2,277
Residue Selling Price	(3,625)	(3,625)	(3,625)
Fixed Bonus	(2,500)	(2,500)	(2,500)
Total	4,091	5,215	6,339

Table F.5.1 Cost range for residue management through rent of Baler for 1st year, with government incentive

F.6 For Full or Partial Burn

	Burn - Full or Partial		
	min	mean	max
Capital/rent	1,000	2,250	1,300
Subsidy	N/A	N/A	N/A
Repair	N/A	N/A	N/A

Diesel	1,000	1,467	2,000
Labor	2,908	3,491	4,565
Fertilizer/Urea	2,810	2,826	2,843
Spray (Insecticides)	1,284	1,561	1,838
Residue Selling Price	N/A	N/A	N/A
Fixed Bonus	N/A	N/A	N/A
Total	9,002	11,595	12,546

Table F.6.1 Cost range for residue management through Burn (full or partial) for 1st year, with government incentive