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"Policy Instruments to Address Air Pollution Issues in Agriculture – Implications for Happy Seeder Technology Adoption in India"

FINAL REPORT

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EXECUTIVE SUMMARY

Background

The rice-wheat farming system dominates agricultural production in north-west India, particularly in the Punjab region where around 2.6 million hectares of rice is grown each year. More than 90 percent of the rice grown in Punjab is harvested using combine harvesters leaving heavy loads of rice stubble in fields. With short timeframes between the harvesting of rice and sowing the proceeding wheat crop, farmers have managed high stubble loads through the practice of burning. At present more than 90 per cent of the 17 million tonnes of rice stubble produced annually in Punjab is burnt.

Although burning is an effective and low cost way of removing rice stubble, there is now widespread concern about its negative environmental, health and production effects. Rice stubble burning results in extensive impacts both on farms (eg losses in soil nutrients, soil organic matter, production and productivity, air quality, biodiversity, and water and energy efficiency) and more broadly (eg off-site air pollution, greenhouse gases, biodiversity loss, and impacts on human and animal health). Farmers and governments at all levels are sensitive to these negative effects and are looking for sound alternatives that are both environmentally sustainable and economic.

The Australian Centre for International Agricultural Research (ACIAR) has been supporting the development of sustainable alternatives to stubble burning through a number of research initiatives in north-west India. As part of ACIAR project LWR/2000/089 *Permanent beds for irrigated rice-wheat and alternative cropping systems in north-west India and south-east Australia*, a breakthrough was achieved in the development of a new generation of seeders, the Happy Seeder. The Happy Seeder is designed for direct drilling wheat into heavy rice residue loads on smallholdings and therefore provides an alternative to stubble burning. It is a tractor-powered machine that cuts and lifts the rice stubble, sows into the bare soil, and deposits the stubble over the sown area as mulch.

Despite the identified on and off-farm benefits and government assistance, to date there has been only a relatively low level of adoption of the Happy Seeder. ACIAR therefore commissioned a further investigation into potential incentives to increase adoption of the technology. The project was undertaken by NSW Trade & Investment in partnership with ACIAR and the National Council of Applied Economic Research (NCAER) in India. The project addressed four main research areas. These included researching the significance of agriculturally based pollution in Punjab and policy measures put in place to control it; summarising the scope of available options to either directly use or manage rice stubbles; considering policy settings and instruments to improve adoption of the Happy Seeder and similar technologies associated with better management of crop stubbles; and reviewing current policies and options related to stubble management practices in Australia.

Economic significance of pollution arising from stubble burning

In India, air pollution from residue burning can be severe, with impacts on human health by directly causing or exacerbating a range of medical conditions and contributing to the incidence of traumatic road accidents through significantly reduced visibility. The survey and economic evaluation conducted in this study show a clear increase in medical and health-related expenditure and work days lost during the rice stubble burning period (September – November) each year. These health-related expenditures tend to be higher for older people and the more wealthy and workers, such as farmers and farm labourers, and rural dwellers who are most directly exposed to rice stubble burning. In this regard, it is notable that 60 per cent of the population in Punjab live in rice growing areas and are hence directly exposed to stubble smoke.

The economic costs associated with the negative health impacts of widespread rice stubble burning in Punjab were estimated only on the basis of the costs of medical and mitigation expenditure and the opportunity cost of workdays lost. On this basis, health costs from rice stubble burning in rural areas of Punjab are estimated at ₹76.09 million annually. Applying this cost to the total quantity of stubble burnt in Punjab each year of 15.3 million tonnes (ie. 90 per cent of 17 million tonnes), gives an estimate of health costs that average ₹4.97 per tonne. These losses should be considered the lower bound of the health damages caused by the increased air pollution level in rural Punjab. They would be much higher if expenses on averting activities, productivity loss due to illness, monetary value of discomfort and utility could be counted and the economic cost of motor vehicle accidents caused by low visibility.

In recognition of these health-related costs and the undesirable farm productivity and environmental consequences of stubble burning, substantial government funding and research and extension effort has been invested in initiatives to reduce this practice. While various initiatives have had some effect, the vast majority of the rice stubble produced in Punjab is still burned in the field. Although there appears to be legal power to limit or even totally ban stubble burning exists under statutes such as the Air (Prevention and Control of Pollution) Act 1981 and the Environment Protection Act 1986, these powers have not been exercised. It is clear that there is a consistent view across government agencies in Punjab that it would be unfair to ban rice stubble burning unless and until there are economic alternatives for farmers.

Stubble management and use options

There are a number of potential options to either directly use or manage rice stubbles. A technical workshop was held in Chandigarh in October 2009 to review available options. The workshop brought together scientists, farmers and policy makers to consider the current and prospective technical feasibility of alternative use options for rice stubble. There was unanimous recognition of the adverse effects of burning rice stubbles and the need to find viable alternatives. Understandably, given the early stages of research in many areas, there was less agreement on which technologies offered the greatest scope for adoption in the longer term.

The ultimate adoption of technologies depends on a large number of factors that concern the underlying characteristics of the technologies as well as the economic and social environment in which they are being introduced. The workshop demonstrated that while there are alternative uses for rice stubble, these could probably account for no more than 10 per cent of the annual stubble load. Alternative uses of rice stubble considered included livestock bedding, power generation, livestock fodder, mushroom cultivation and paper and pulp board manufacture. It was also concluded that the management of rice stubbles in-field through the Happy Seeder and similar technologies have the greatest prospects for reducing the incidence of stubble burning in the short to medium term.

Policy settings to improve the adoption of more sustainable technologies

The third major area of work involved the consideration of potential policy settings and instruments to improve adoption of Happy Seeder and similar technologies. As a pre-cursor to considering new policy settings, a review of historical government policy settings was also undertaken. The review highlighted that agriculture in India and in north-west states like Punjab, was transformed through the period of the Green Revolution. The period marked the arrival of imported varieties of rice and wheat and increased use of inputs such as chemical fertilisers, herbicides, insecticides, pesticides and irrigation. Many of these inputs, including fertiliser, seeds and electricity used for irrigation were subsidised. Adoption of the new varieties and production technologies was also aided by programs to subsidise the purchase of farm machinery, ensure access to credit, and to support farm-gate prices for food grains and other major crops. The response to the incentives created through these interventions in Punjab was for agriculture to largely transition to an intensive rice-wheat double-cropping system.

While policies have to some extent delivered on objectives relating to expanded production of key food crops, such as rice and wheat, and price stabilisation for consumers, there are strong and increasing concerns about sustainability of the farming system that has been created. Moreover, many of the same policy settings that exist today act to limit the emergence of more sustainable solutions that address environmental concerns. This is principally because such policies undervalue the key resources (water, electricity, fertiliser, fuel) saved. An important part of the research therefore was to review the extent to which these more general policy settings might influence the private incentives for adoption of the Happy Seeder.

To assess the influence of policy settings on land use and technology adoption (including Happy Seeder), a farm level model of agriculture in Punjab was developed. The model seeks to maximise farm income by selecting the most profitable set of land uses, technologies and management practices, subject to constraints on resources (land, labour, capital, water). Key resources (eg., water, electricity, fertiliser) and outputs (crop yields, stubble production, CO2-e emissions) were identified separately to facilitate an assessment of changes to policy settings which affected their values.

The first scenario tested current policy settings, incorporating current subsidies, against a new set of policy conditions where electricity and fertiliser were fully priced. The model was optimised under these alternative policy settings, with the set of enterprise options constrained to those most commonly observed on farms in Punjab (wheat, rice and maize). Under current policy settings, the farm was dominated by rice and wheat production and Happy Seeder was not selected. The model was then solved under the assumption that current subsidies on electricity and fuel were removed. Model results show a switch from electrical pump to diesel pump use, show a small reduction in farm income, rice area and water use and Happy Seeder is selected.

The second scenario involved the same policy settings as the first scenario, but with flexibility to broaden the traditional farming system beyond those crops widely practised. A benefit of direct drill technologies, such as the Happy Seeder, is time savings that create the potential for a further short-duration crop to be grown. Under current subsidies, the model results show a full area of rice and wheat being planted (using Happy Seeder) but a third crop of Mungbeans is also included as a consequence of time savings made possible by direct drilling using Happy Seeder. Removing electricity and fertiliser subsidies reduces farm income, triggers a switch from electrical pump to diesel pump use but the land uses remain the same as in the 'with subsidy' case. Happy Seeder is found to be a profitable technology, in case both 'with' and 'without subsidies'.

The third scenario involved subsidising the cost of Happy Seeder, with the value of that capital subsidy being reflected in a lower contract rate being faced by the farm model. Its worth noting that a capital subsidy has only a moderate effect on the contract rate because there are other costs reflected in the contract rate that remain unaffected by a subsidy (eg. all costs related to running the tractor). We find that a capital subsidy of around 25 per cent is sufficient to encourage adoption. However, the results are also found to be very sensitive to even slight changes in key parameters that could easily be driven by small changes in soils, climatic conditions or management skills within or across production regions. In simulations undertaken, even a 2 per cent improvement in the yield of wheat established with Happy Seeder was sufficient for the technology to be included in the optimal farm plan, without any subsidy at all on the capital cost of the technology.

In the final scenario, two options were assessed which directly placed a price on the practice of stubble burning. The first was modelled as a tax directly on the quantity of stubble burnt, with the tax set to reflect the costs of the adverse health impacts of local pollution. With current policy settings in place, imposing a conservative estimate of calculated health costs (₹4.97 per tonne) was not sufficient to trigger the adoption of Happy Seeder. In fact, a threefold increase in the estimated health cost to around ₹14.00 per tonne was required for this to occur. The second option was to introduce a price on CO2-e emissions, reflecting regional/global concerns about climate change. A carbon price was varied from ₹50-500/tonne of CO2-e (US$1-10/t). A price of ₹250/tonne (US$5/t) was found to be sufficient to encourage the adoption of Happy Seeder. If a carbon price was to be introduced through an agricultural offsets scheme, then this would result in farmers actually receiving additional income from reducing stubble burning at the same time as reducing local pollution effects.

In considering the efficiency of different policy settings to address the practice of stubble burning, we identified a number of key principles that should be applied to particular interventions. These included:

- that they should be clearly focussed on addressing the mischief being cured (air pollution and other environmental and social costs of rice stubble burning), and if possible should harness private interest to achieve this goal;
- that they should as closely as possibly represent minimum intervention, market-based solutions and hence be consistent with OECD micro-economic reform principles;
- that they should reflect an understanding of the broad economic, social and historical context in which the rice-wheat farming system in Punjab has its origins; and
- that they should not act to entrench other policies or programs that provide counterproductive incentives.

From an economic policy perspective, it is preferable to first reform existing policy settings which otherwise limit the gains from the adoption of more sustainable technologies generally. Subsidies on electricity and fertiliser were shown to limit the gains from technologies like Happy Seeder which save on those inputs. We find that exposure to unsubsidised market prices for electricity and fertiliser, while marginally effecting rice production, increases the attractiveness of Happy Seeder and may encourage adjustment to a farming system that is only marginally less profitable, generates less air pollution and uses less fertiliser, fossil fuel and water inputs.

A key benefit of reforming general policy settings, over providing assistance to specific technologies, is that it gives flexibility to farmers to respond to market signals in the most efficient way. In some cases, farmers may choose the promoted technology, but in other cases may decide to switch crops or management practices. This is more efficient than prescribing the adoption of a certain technology which may not be the most economic option in all circumstances. Subsidies on particular technologies should be limited to expanding the demonstration of the technology to other sites to address uncertainties about the extent of benefits. Such an approach will increase the rate of adoption of beneficial technologies but generally will not influence final adoption levels.

From a broader economic perspective, reform of policy settings within agriculture may have significant benefits to other sectors. Subsidised electricity supplies for example is not only putting pressure on the capacity of electricity infrastructure and imposing associated costs on other sectors, but is also leading to over exploitation of groundwater resources across Punjab. Although major reforms invariably meet resistance, there are ways in which some of this resistance can be addressed through the design of alternative policy instruments. In the context of electricity pricing for example, a credit-rebate scheme could be introduced that would credit farmers with the average cost of their historical use of electricity as a lump sum. Farmers would then be charged on the basis of their marginal use. Such a system would provide incentives for more efficient use of electricity and water without making farmers necessarily worse off.

Current policies and options for stubble management in Australia

The report also reviewed stubble management policies in the Australian rice industry. Stubble burning in NSW, Australia is not prohibited and is in fact quite a common practice. The much smaller area of rice, combined with much lower population density where rice is grown, does not impose the same health concerns as those experienced in the densely populated areas of Northern India.

The analysis supports current practice of burning rice stubbles as the most profitable option for Australian farmers under existing policy settings. In the absence of any tightening in policy settings around the burning of stubbles, or the development of carbon offset markets or alternative uses of rice, that reward farmers for stubble retention, it seems that stubble burning will remain widespread.

1. INTRODUCTION

1.1 The Changing State of Punjab Agriculture

1.1.1 Agricultural Policy Environment

In the early 1960s, agriculture on the Indo-Gangetic Plains of north-west India and in Punjab more specifically, was largely characterised by dryland production systems with very low levels of purchased inputs. While wheat was the major crop as it is today, there was only occasional opportunistic double-cropping, and production of coarse gains and pulses far exceeded rice. Just over forty years later, however, the area under cultivation has expanded enormously and high-input, rice-wheat double cropping has become the dominant farming system (see Table 1.1). To understand the fundamental change that has taken place over this period, in terms of the area under crop, the production system and the crop mix, it is necessary to understand the nature of the policy settings in which the agriculture sector has developed.

Table 1-1: Trends in Crop Area in Punjab

Crop	Year			
	1960-61	**1980-81**	**2000-01**	**2004-05**
	'000 ha	'000 ha	'000 ha	'000 ha
Rice	227	1,183	2,611	2,647
Wheat	1,400	2,812	3,408	3,482
Maize	327	382	165	154
Cotton	446	648	474	509
Pulses	903	341	61	40
Oil seeds	185	248	87	91
Sugarcane	133	71	121	86
Total	**3,621**	**5,685**	**6,927**	**7,009**

Source: Government of Punjab

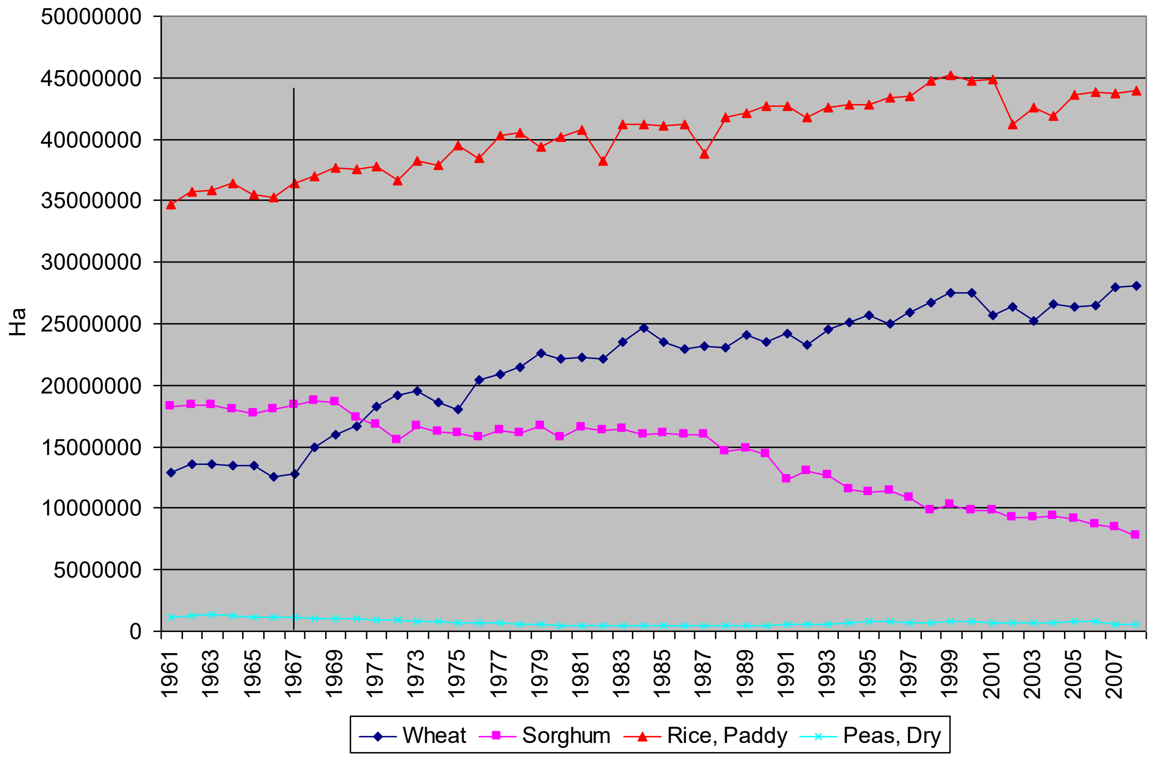
A key objective of the Indian independence movement was to put in place institutions and policies that would (i) eliminate recurrence of the famines that had occurred during the colonial period, and (ii) ensure that basic foods were available to the whole population at affordable prices. In order to achieve these objectives, the government intervened in foodgrain markets from the late 1940s (Pursell *et al* 2007). However, droughts in the 1960s led to a crisis in 1966, when India produced only 72 million tons of grain and import dependency more that doubled (USDA 2004).

In the same year there was a 30 per cent[1] devaluation of the rupee against the pound and the US dollar. This substantially increased the cost of imports, accentuating the difficulties for the populace (and hence the government) associated with a high level of import dependency. *"In agriculture, one of the outcomes of the devaluation… was to reinforce the determination to become self-sufficient in food grains and other basic agricultural products"* (Pursell *et al* 2007, 12). After the 1966-67 food crisis and because of concern with rising dependence on imported grain, India advanced the policy initiative now termed the Green Revolution.

The Green Revolution focussed on increasing food production by substantially improving agricultural productivity. The program was started with US aid and was based on high-yielding varieties of rice and wheat (developed at CYMMT in Mexico and IRRI in the Philippines, respectively). A key strategy was to modernise agricultural practices and inputs in the most productive areas of the country. The impact was immediate:

[1] Nominally 57.5 per cent, but estimated to be around 30 per cent in real terms (Pursell *et al* 2007).

Figure 1-1: Crop Production – India



Source: FAO

> *"In 1967, then-Prime Minister Indira Ghandi imported 18,000 tons of [high yielding] wheat seeds from Mexico. The effect was miraculous. The wheat harvest that year was so bountiful that grain overflowed storage facilities* [see Figure 1.1]. *Those seeds required chemical fertilizers to maximise yield."* (Anand 2010)(bracketed terms added)

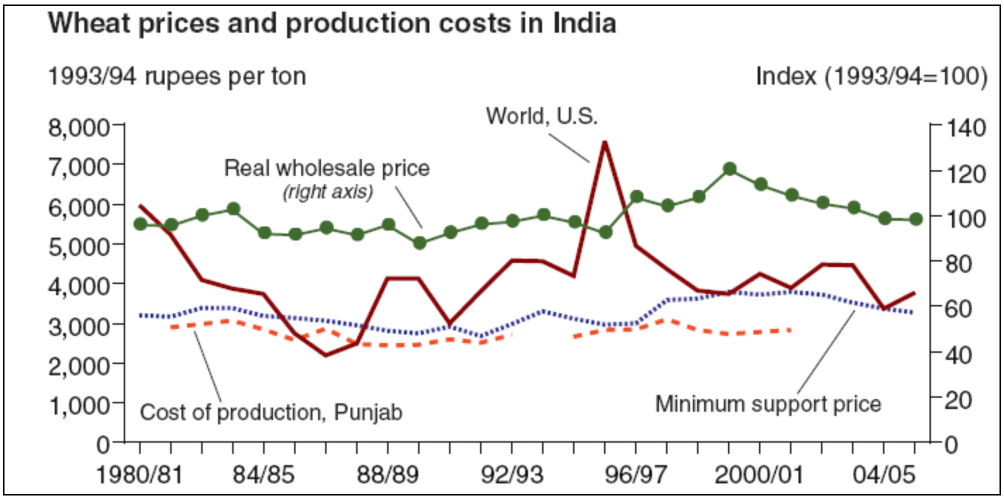
Agriculture in India and in north-west states such as Punjab in particular, has been transformed since the beginning of the Green Revolution.

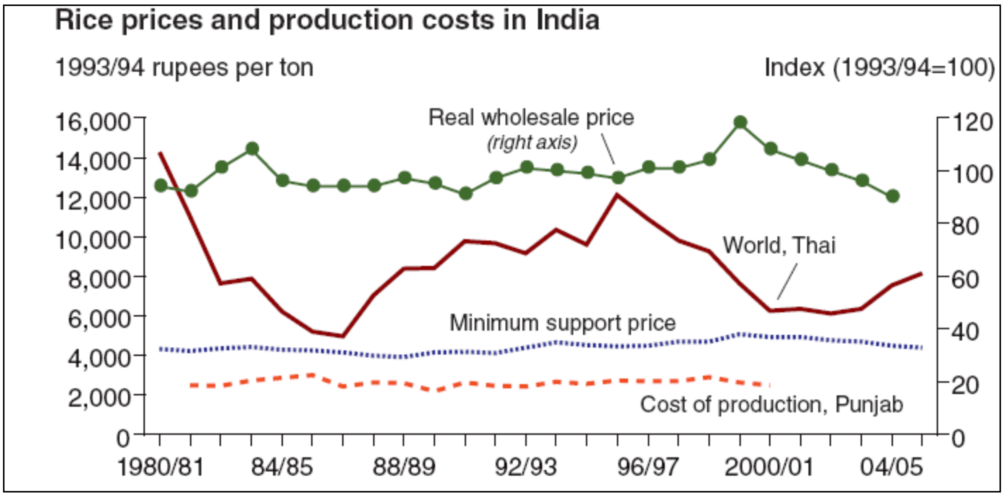
The Green Revolution was marked by the arrival of imported varieties of rice and wheat and increased use of inputs such as chemical fertilisers, herbicides, insecticides, pesticides and irrigation. Many of these inputs, including seeds and the electricity used for irrigation and other agricultural purposes, were subsidised (Davenport *et al*. 2009). Adoption of the new varieties and production technologies was aided by programs to subsidise the purchase of farm machinery, to ensure farmers ready access to credit[2], and to support farm-gate prices for food grains and other major crops (USDA 2004).

The policy package included (and still includes) minimum support prices (MSPs) for major crops. The MSPs are based on costs of production, including variable inputs, rental value of land, imputed value of family labour, and a 10 per cent return to management (Jha *et al*. 2007). While the MSPs for rice and wheat have tapered down in recent years, they have traditionally been well above the cost of production in Punjab, particularly for rice (Figure 1.2). At the same time, however, through export restrictions, domestic producer prices have generally been maintained below international reference prices (Pursell *et al* 2007).

[2] In Punjab, for example, farmers pay a lower interest rate and have easier collateral and ability to pay requirements than other borrowers (Dr's Sandhu and Sidhu, Punjab Department of Agriculture, pers. comm., September 2008).

Figure 1-2: Wheat and Rice Prices and Production Costs





Source: USDA (2007)

Overall, from the perspectives of food production, consumer affordability and stabilisation of domestic food prices, the Green Revolution and associated policy interventions have been, at least until recent times (see section 1.1.3), a success story:

- *"Indian agriculture has, since Independence, made rapid strides. In taking the annual foodgrains production from 51 million tonnes of the early fifties to 206 million tonnes at the turn of the century*[3]*, it has contributed significantly in achieving self-sufficiency in food and in avoiding food shortages in our country."* (Department of Agriculture and Cooperation 2009b)

- *"India achieved strong growth in food grain production… because of its extensive agricultural resource base, the introduction of high-yielding grain varieties, and supportive government policies. This enabled India to achieve its key policy goal of self-reliance in cereals during the 1990s and 2000s."* (USDA 2009)

- Punjab agriculture is characterised as the backbone of India's public distribution system and a strong base for national food security. Food grain output in Punjab rose from 3.16 million tonnes in 1960-61 to 25.31 million tonnes in 2006-07. While comprising just 2.6 per cent of the cropped land in India, in 2006-07 Punjab produced about 20 per cent of the total national

[3] Now 230 million tonnes at the end of the first decade of the 21st century.

output of wheat and 11 per cent of the rice and cotton. Punjab agriculture makes an even larger contribution to the central food pool, generally supplying in excess of 60 per cent of the wheat intake (75.3 per cent in 2006-07) and 30 per cent of the rice (31.2 per cent in 2006-07).

- *"Between 1965 and 1988, domestic rice and wheat prices declined by 44 per cent and 52 per cent in real terms. Because of steadily increasing farm productivity, this major long-term benefit to consumers was compatible with increasing farmer prosperity, especially in north west India. …the trade policy regime of the period kept the prices of principal food grains low."* (Pursell *et al* 2007, 26)

- The Indian Government's policies have proved very successful at stabilising domestic prices and insulating domestic markets from fluctuations in world prices, particularly for key commodities such as rice (Pursell *et al* 2007).

- *"The insulating role of policy measures is especially clear in terms of India's main food staple, rice, whose domestic price in real terms has been kept very stable over the past 41 years* [1965 to 2004]*… Sugar is another example… As for rice, domestic sugar prices have been kept quite stable for long periods, and have steadily declined over time in real terms."* (Pursell *et al* 2007, 20-21)(bracketed term added)

1.1.2 Farming System Response in Punjab

The support programs implemented during the Green Revolution have helped India become a surplus producer of a number of cereals. In the process, however, the Government of India institutionalized policies and programs which, despite appearing to have a broad base across the cropping sector, have in reality strongly favoured wheat and rice (USDA 2004). Production of coarse grains – the staple diet of the poor – and pulses – the main source of protein – has lagged behind, resulting in reduced per capita availability (USDA 2004).

> *"… the development and use of high-yielding varieties, irrigation, and modern inputs has been slow to spread beyond wheat and rice production."* (USDA 2009)

> *"Paddy and wheat farmers are the main beneficiaries of the fertilizer subsidy, followed by cotton and sugarcane farmers."* (Fan *et al*, 2007 5)

Punjab - a state with large areas suitable for growing rice and wheat and with both surface and groundwater resources and requisite irrigation and infrastructure facilities - was a major beneficiary of the Green Revolution.

> *"Subsidies on electricity, used mostly for pumping groundwater for irrigation, and for government-built canals, combine to significantly reduce farmer costs of irrigation. The benefits are spread across the irrigated areas of the country, but the wheat-rice-sugarcane growing areas of Punjab, Haryana, and Uttar Pradesh, and rice-growing areas of Andhra Pradesh, have reaped particularly large shares of the benefits."* (USDA 2004, 6)

> *"As a percentage of agricultural GDP, Madhya Pradesh, Gujarat, Andra Pradesh, Punjab and Tamil Nadu received the most subsidies in 1997-99, ranging from 15 to 21 percent… In terms of subsidies per hectare of cropped land, Tamil Nadu, Punjab, Gujarat, and Andra Pradesh were among the top recipients… In general the western states, including Punjab, Haryana, and Gujarat, benefited the most…"* (Fan *et al*, 2007 8)

In Punjab, the response to the incentives created through these interventions and the yield advantages of the new varieties over others under irrigation and chemical fertilisers has been for agriculture to in large part transition to a rice-wheat double-cropping system. Timeliness of field operations is a key element in fitting both crops in a year and achieving high yields (Singh *et al*. 2008). In Punjab, given ready access to water, fertilisers and short duration varieties it became possible to grow a rice crop (June-July to October-November) followed by a wheat crop (November-December to March-April). This allowed the introduction of a double crop rotation in areas that formerly could produce only rice or wheat in a single year.

The advent of mechanical harvesting (supported by subsidies and access to credit) assisted this by substantially reducing the duration of the rice harvest, thereby reducing both the risk of a rice crop failure and the risk of missing the relatively short planting window for wheat. Risk was also reduced by the MSP program and government procurement arrangements which effectively guaranteed prices for rice and wheat (USDA 2004)[4], and induced farmers to shift their production to these crops from coarse cereals, pulses and even oilseeds, especially in Punjab and Haryana (Chada 2009; PTI 2004 cited in Prahadeeswaran *et al*. 2005). In these states, production of these crops boomed (Table 1.1 and Figure 1.3).

In addition to double-cropping, rice is now also grown on light to medium texture soils which were traditionally growing maize, pulses and oilseeds, and continuous rice-wheat rotation has expanded to now be more than 2.6 million hectares or 60 per cent of the total sown area in Punjab (Singh *et al.* 2008). About 90-95 percent of the rice area is under the intensive rice wheat system (Gadde *et al*. 2009).

1.1.3 Undesirable Policy Outcomes

While food production, consumer affordability and domestic food price stabilisation objectives have largely been met, it is now becoming apparent that these benefits have come at some environmental and social cost and there are strong concerns over the sustainability of the farming system.

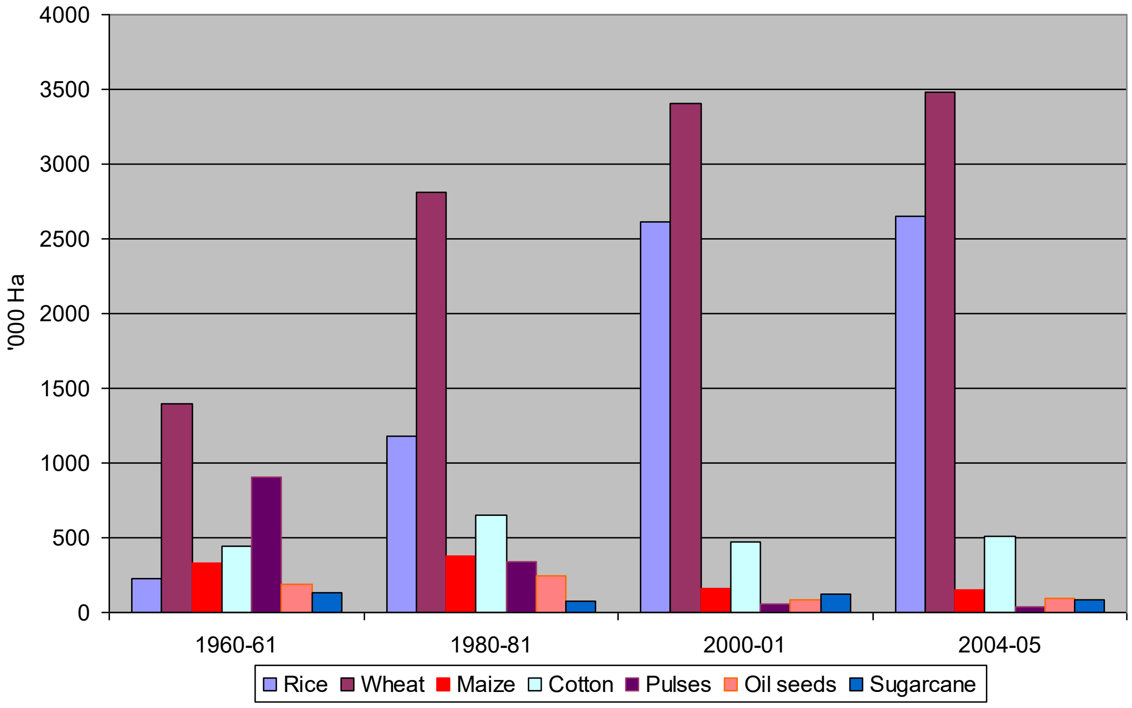
> *"In the name of helping the farmer and the consumer, and likely even with the earnest intention of doing so, we have ended up creating a foodgrains policy framework that has not got high marks on either account. Many of India's poor households do not get adequate, nutritious food and many of our farmers remain impoverished, especially the small ones with no marketable surplus."* Basu (2010)

> *"Considerable input subsidies, in particular for fertilisers, …are not an effective way of providing income support for farmers as only a small fraction of such transfers is effectively received by farmers. Moreover, such payments do not encourage farmers or suppliers to improve efficiency and lead to an overuse of inputs with negative environmental benefits." (OECD 2009, p95)*

> *There are two basic types of environmental problems associated with agriculture. Most of the successful breakthroughs in productivity have occurred in more favoured agroecological zones and have been based on intensive use of irrigation water, fertilizers, pesticides and other modern inputs (eg., the Green Revolution). Agriculture based on intensive use of modern inputs is prone to mismanagement that leads to environmental degradation."* (Hazell 1998, ix)

[4] Each year, the Government of India purchases around 15-20 per cent of India's wheat production and 12-15 per cent of its rice production (Food Corporation of India 2010).

Figure 1-3 Crop Production – Punjab



Source: Government of Punjab

"The pattern of growth of agriculture has, however, brought in its wake, uneven development, across regions and crops and also across different sections of the farming community and is characterized by low levels of productivity and degradation of natural resources in some areas." (Department of Agriculture and Cooperation 2009b)

"In the 1970's, India's agricultural policy was based on policies of food security and price stability. Policy settings included controls on market pricing, storage, transport, and quantitative restrictions on trade. Public investment in the agriculture sector, spurred on by 'The Green Revolution' of the 1960s, grew by over 4 percent per annum in the 1980s. This rate, however, was not sustainable. A slowdown in public investment, low yield growth, and environmental problems including declining water tables led to poorer agricultural performance in the 1990s." (Davenport *et al*. 2009)

"…there is also growing evidence that the system of intensive double-cropping of wheat and rice in the Indo-Gangetic Plain region – where most of India's surplus wheat and rice is produced – now faces constraints associated with depletion of soil and water resources and pest problems…" (RWC-CIMMYT 2003 cited in Jha et al. 2007, 3-4)

The [electricity] *subsidy has contributed to over-pumping and wasteful use of energy and groundwater, causing an increasingly serious problem with depletion of groundwater resources in some areas."* (USDA 2004, 6)(bracketed term added)

"Power subsidies have prompted the expansion of groundwater irrigation… In some areas, particularly in north India where intensively irrigated wheat and rice have become common, agriculture is increasingly threatened by water logging and salinity problems associated with high rates of canal irrigation and extraction of groundwater (Gulati & Narayanan 2003; Gulati et al 2005)." (cited in Landes 2008, 30)

"India has been providing farmers with heavily subsidised fertilizer for more than three decades. The overuse of one type - urea - is so degrading the soil that yields of some crops are falling and import levels are rising... In the state of Haryana, farmers used 32 times more nitrogen than potassium in the fiscal year ended March 2009, much more than the recommended 4-to-1 ratio, according to the Indian Journal of Fertilizers, a trade publication. In Punjab state, they used 24 times more nitrogen than potassium… This type of ratio is a disaster…" (Anand 2010)

Mr Singh farms 10 acres in Sohian, a town about 25 miles from the industrial city of Ludhiana. He said his yields of rice have fallen to three tons per acre, from 3.3 tones five years ago. By using twice as much urea, he's been able to squeeze a little higher yield of wheat from the soil – two tons per acre, versus 1.7 tons five years ago"… Adding urea doesn't have the effect it did in the past, he said, but it's so cheap that it's better than adding nothing at all." (Anand 2010)

"Land needs to be watered more when fertilizer is used, and Mr Singh worries about the water table under his land. When his parents dug the first well here in 1960, the water table lay 5 feet below the ground, he says. He recently had the same well dug to 55 feet to get enough water." (Anand 2010)

"Electricity subsidies are paid from state budgets to the providers of electricity, and result from the difference in the cost of electricity provision and fixed charges paid by farmers. As these subsidised charges do not reflect the actual cost, they encourage overuse of electricity and lead to overexploitation of groundwater." (OECD 2009, p104)

In addition to the many problems outlined above, a particular issue is the practice of rice stubble burning (Figure 1.4). Due to the heavy stubble loads generated by high yielding rice varieties, time pressure between rice harvest and wheat planting, rising labour costs[5] and subsidies that have promoted mechanisation, management practice has shifted away from hand harvesting to combine harvesting[6]. This process leaves high volumes of anchored stubble in the field (more than 6 tonnes per hectare), for which a management solution must then be found. The residues of high yielding rice varieties have high silica content and are of little value on-farm for stockfeed, particularly in a system that also produces wheat stubble.

Figure 1-4: Burning of Rice Stubbles Prior to Sowing Wheat in Punjab

[5] According to the Punjab Department of Agriculture, in recent years labour shortages and rising wages have pushed rice planting costs up 6-fold from 300 to 1,800 rupees per acre (Dr's Sandhu and Sidhu, pers. comm., September 2008).
[6] In a farm household survey conducted in the Patiala district of Punjab in 2009, less than 7 per cent of the respondents harvested their paddy manually (Kumar and Kumar 2010).

While stubble is in some respects an alternative to fertiliser in preparing the soil for planting, with the availability of cheap (subsidised) fertiliser the more costly options of stubble incorporation or application as mulch are unattractive to farmers. Also, late harvesting of rice results in late planting of wheat and may cause significant yield penalties. As tillage to incorporate rice residues is time consuming and exacerbates the risk of late wheat planting, farmers have to a large extent resorted to burning off rice residues prior to planting wheat.[7]

A large volume of wheat and rice stubble is produced annually in Punjab. Around 17 million tonnes of rice stubble is produced from about 2.6 million hectares of paddy. It is estimated that around 90 per cent of the rice residue is burned over a relatively short period after harvest in September/October/November each year (Singh *et al* 2008)[8]. Wheat stubbles have economic uses, mainly as stockfeed, so are not burned.

Stubble burning causes air pollution (particulates, greenhouse gases), nutrient loss (especially nitrogen and carbon, but also potassium, phosphorus and sulfur) and soil organic matter decline, and impacts on human health both medically and by traumatic road accident due to restricted visibility (Kumar and Kumar 2010). This practice thus has both deleterious on-farm production affects and poses a substantial community problem. Moreover, agricultural biomass burning comprises 15 per cent of agriculture's greenhouse gas (GHG) emissions, which in turn comprise 29 per cent of India's total emissions (Gujral *et al* 2010). That is, agricultural biomass burning on its own is the source of 4.4 per cent of India's total GHG emissions. [9]

In summary, while this system is considered to be very important to Indian food security:

- productivity is low by world standards (USDA 2004);
- water consumption is high and groundwater supplies are being depleted (Department of Agriculture and Cooperation 2009);
- soil fertility is declining and fertiliser rates are excessive and rising (Anand 2010);
- energy (electricity and diesel) demand is high;[10]
- at least in Punjab, rice stubble is largely burned in the field, giving rise to air pollution and negative on-farm productivity consequences; and
- the subsidy programs are very costly to government.[11]

Farmers and the Punjab Government are sensitive to the economic and social costs of rice stubble burning and are looking for viable alternatives. The Punjab Government, for example, has been providing subsidies for farm equipment that reduces soil tillage and burning of stubble. During the year 2007-08 around 2,659 rotavators, 1,383 zero till drills, two Happy Seeders (see section 1.2) and 448 stubble reapers were distributed to farmers on subsidy by the Department of Agriculture (Kumar and Milham 2010).

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[7] In a survey conducted in the Patiala district in this project, around 90 per cent of households fully burnt the field to remove the crop residue (Kumar and Kumar 2010).

[8] A survey of farmers in the Patiala district of Punjab in 2009 found that more than 85 per cent of paddy stubbles were burned (Kumar and Kumar 2010).

[9] Through both its production system and stubble burning, rice is the main 'culprit' crop for smoke pollution and greenhouse gas emissions (Prof S.S. Johl, personal communication, October 2010).

[10] According to Jha *et al*. (2007), the cost of providing free or subsidized (depending on the State) electricity for agriculture accounts for more than two-thirds of total input subsidies. Furthermore, the agriculture sector consumes 29 per cent of power generated, but contributes only 3.36 per cent of electricity sales revenue (Fan *et al.* 2007).

[11] The total cost was estimated at US$11.9 billion in 2005/06, accounting for about 15 per cent of total government expenditure in that year (Jha *et al.* 2007).

The Australian Centre for International Agricultural Research (ACIAR) has been also supporting the development of alternatives to stubble burning through a number of research projects. The development and continued refinement of the so-called Happy Seeder machine, designed for direct seeding into fields with heavy stubble loads in small-scale farming systems, is a key outcome of the ACIAR-sponsored research.

1.2 Project Overview

As part of ACIAR project LWR/2000/089 *Permanent beds for irrigated rice-wheat and alternative cropping systems in north-west India and south-east Australia*, a breakthrough was achieved in the development of a new generation of seeders, the Happy Seeder (Figure 1.5). Further refinement of the Happy Seeder continued in ACIAR project CSE/ 2006/124 *Fine-tuning the Happy Seeder technology for adoption in northwest India*.

The Happy Seeder is designed for direct drilling wheat into heavy rice residue loads on smallholdings and therefore provides an alternative to stubble burning. It is a tractor-powered machine that cuts and lifts the rice stubble, sows into the bare soil, and deposits the stubble over the sown area as a mulch. It combines the stubble mulching and seed and fertiliser drilling operations into one machine in a single pass (Sidhu *et al*. 2007, 2008).

As part of this research, a simple preliminary financial analysis was undertaken which suggested that investment by farmers in the Happy Seeder technology would be financially viable (Singh *et al*. 2008, 2009).

The Happy Seeder therefore appears to have considerable promise to provide environmental and community benefits as an alternative to burning as a means of managing rice residues. Field trials indicate that it also offers on-farm benefits through higher crop yields, increased cropping opportunities, less weed growth, improved soil quality and structure and lower water consumption – an important feature given concerns about declining water supplies (Singh *et al*. 2008).

Despite the identified on- and off-farm benefits and government assistance, to date there has been only a relatively low level of adoption of the Happy Seeder. ACIAR therefore commissioned a further investigation into potential incentives to increase adoption of the technology. CSE/2006/132 *Policy instruments to address air pollution issues in agriculture - Implications for Happy Seeder technology adoption in India* was undertaken by the NSW Department of Industry and Investment in Australia (I&I NSW) in partnership with ACIAR and the National Council of Applied Economic Research (NCAER) in India. The project was focused on the effectiveness and desirability of increasing government subsidies for the purchase of Happy Seeder machines in the combine harvested, rice-wheat farming system of north-west India.

The private incentives for adoption of the Happy Seeder depend upon the production economics of the technology; policy and market signals relating to enterprise selection and input management; and government policy in relation to prevention of pollution and other off-farm impacts of management practices. In addressing these questions, it was necessary to give consideration to both:

1. the farm-level incentives (and disincentives) for private investment in a Happy Seeder (it is only through understanding of the incentive structures that lead to the practice of stubble burning that the nature and extent of changes to those incentives to promote desirable change can be identified); and
2. the broader objectives of agricultural policy that may be sought to be delivered through increased adoption of the Happy Seeder technology and whether or not increased public

subsidies would in principle be an efficient and effective mechanism for achieving those benefits.

Figure 1-5: The Happy Seeder Direct Drilling Wheat in Standing Rice Stubble

The project investigated the significance of rice stubble burning as a source of air pollution in Punjab and the economic or monetary costs on human and animal health. Based on the findings, the project aimed to provide policy suggestions on pollution issues. The financial and economic performance of the Happy Seeder relative to other technically feasible rice residue use and on-farm management technologies was analysed, and an array of potential policy instruments to reduce air pollution from rice farms was identified and evaluated.

The project addressed an important public policy and farm management issue and received a high level of cooperation from both government agencies and farmer representatives. Productive relationships were established with the Punjab Department of Agriculture and the Agriculture Technology Management Agency, Punjab Agricultural University, Punjab State Farmer's Commission, Punjab State Council for Science & Technology, Punjab State Planning Board and the Punjab Pollution Control Board.

2. AGRICULTURALLY-BASED AIR POLLUTION IN PUNJAB

2.1 The Significance of Agricultural Air Pollution[12]

2.1.1 Introduction

It is a common misconception that the industrial sector is the only contributor to air pollution, whereas agriculture also contributes significantly to pollution in various ways. Open field burning of crop stubble results in the emission of many harmful gases in the atmosphere, like CO, N_20, NO_2, SO_2, and CH_4, along with particulate matter and hydro carbons (Kumar & Joshi 2010): India annually emits 144,719 tonnes of total particulate matter from open field burning of rice stubble (Gadde *et al*. 2009).

Epidemiological studies show that contamination of air increases adverse health impacts (Ostro *et al*. 1995). Air pollution contributes to respiratory diseases like bronchitis, emphysema, asthma etc., and eye irritation, which not only increases individuals' diseases mitigation expenses but also affects their productivity at work. While it is known that many of the components of agricultural smoke may cause health problems under certain conditions (Long *et al. 1998*), to date most studies valuing the health impacts of air pollution remain confined to urban areas as air pollution is considered mainly an urban problem in developing countries. As the health costs of burning of agricultural residues are not well understood, a key component of this project was to attempt to value the health effects of rice residue burning in rural Punjab. Information on the nature, extent and cost of the health related impacts of residue burning will help inform decisions on the appropriate policy response.

There are many studies in developed countries that value the adverse health effects of air pollution (eg., Gerking and Linda1986, Dockery *et al*. 1993, Schwartz, 1993, Pope *et al*. 1995 etc). Similar evidences are available from India and other developing countries (eg., Cropper *et al*. 1997, Kumar and Rao 2001, Murty *et al*. 2003, Gupta 2008, Chestnut *et al*. 1997, Alberini and Krupnick 2000). These studies used either household health production models, damage functions or cost of illness approaches to estimate the monetary value of health damage caused by ambient air pollution. Cropper *et al* (1997), using a dose-response model, found that a 100-µg/m3 increase in total suspended particulate matter (TSPM) led to a 2.3 per cent increase in trauma deaths in New Delhi.

Kumar and Rao (2001) estimated a health production function using household data from the residential complex of Panipat Thermal Power Station in Haryana and found that individual willingness to pay varied between 12 to 53 rupees per month for improving the air quality to WHO standards. Using a similar model, Murty *et al* (2003) observed that a representative household gained about 2,086 and 950 rupees per annum due to reduced morbidity from reduction of air pollution to the safe level in New Delhi and Kolkata, respectively. Similarly, Gupta (2008) estimated aggregate benefits of 225 million rupees per year from reducing air pollution to the safe level for the city of Kanpur.

In the present study, a consumer choice model was used to derive a monetary value for the health benefits of reducing air pollution to the safe level for rural Punjab. Data were collected from 150 households (625 individuals) through a household level survey conducted in three villages in the Patiala district of Punjab. To get the monetary values, two equations were estimated: one with mitigation expenditure and the other with workdays lost as dependent variables. Tobit and Poisson models were found to be suitable for estimating the mitigation expenditure and workdays lost equations, respectively.

[12] This section is largely drawn from Kumar and Kumar (2010).

2.1.2 Ambient Air Quality Level in the Study Area

While Central and State Pollution Control Boards have been monitoring the ambient air quality for certain Indian cities for the last two decades, monitoring of ambient air quality in rural areas is very sporadic and purpose specific. However, due to the severity of the smoke problem from rice residue burning, the Punjab Pollution Control Board (PPCB) conducted air pollution monitoring in three rural villages in the Patiala district (Dhanouri, Simro and Ajnauda Kalan) during November 2006.

Monitoring stations for the sites were planned keeping in view the metrological conditions and environmental settings in terms of habited and non-habited areas. The following factors were monitored:

- metrological parameters (temperature, humidity, wind speed and wind direction);
- particulate matter ($PM_{2.5}$, PM_{10}, TSPM);[13]
- gaseous pollutants (SO_2, NO_x, NH_3, CO, O_3, THC, TC and BTX); and
- heavy metals.

The Central Pollution Control Board has defined National Ambient Air Quality Standards (NAAQS) which indicate that human health is threatened once air pollutants exceed the following thresholds:

	Annual daily average	24-hour average
• SO_2	60 µg/m^3	80 µg/m^3
• NO_x	60 µg/m^3	80 µg/m^3
• PM_{10}	60 µg/m^3	100 µg/m^3

Descriptive statistics of some of the important pollutants and metrological parameters measured at Dhanouri, Simro and Ajnauda Kalan in 2006 are given in Table 2.1. These data show that gaseous pollutants such as SO_2 and NO_x were within the NAAQS safe limits. However, concentrations of particulate matter exceeded the safe limits.

In the study area, all the particulates followed the same pattern in whatever terms they were measured. The hourly peak values ranged between 300-350 µg/m^3 and the 24-hour average concentration ranged between 200-300 µg/m^3. The ratio between peak and average values was found to be about 1.2, indicating an almost uniform concentration over the monitoring period.

Table 2-1: Descriptive Statistics of Emissions and Metrological Data at Dhanouri, Simro and Ajnauda Kalan, Punjab, November 2006

	PM_{10}	SO_2	NO_x	Relative Humidity (min)	Wind Speed	Temperature (maximum)	Temperature Difference (max minus min)
	µg/m^3	µg/m^3	µg/m^3	%	km/hr	^{0}C	^{0}C
Mean	306.66	14.20	56.08	46.13	1.78	29.35	16.87
Std Dev	16.60	2.96	12.32	0.97	0.40	0.60	1.05
Maximum	325.5	17.4	69	47.4	2.35	30.2	18.2
Minimum	284.75	10.25	39.25	45.1	1.425	28.8	15.6

Source: Punjab State Pollution Control Board (2006)

[13] The notation PM_{10} is used to describe particles of 10 micrometers or less in aerodynamic diameter. $PM_{2.5}$ represents particles less than 2.5 micrometers.

The contribution of rice stubble burning to PM_{10} concentration appeared to be around 100-200 µg/m^3 (Punjab State Pollution Control Board (2006). At all three monitoring sites, the difference in humidity and temperature levels was negligible and the wind speed was low (0 -3.6 km/hr). Low wind speed coupled with low wind direction fluctuation implies that the impact of polluting activities remains confined to the close vicinity.

2.1.3 Household Survey Design and Data

To build on the earlier work by the PPCB and go on to measure the economic cost of pollution, data on socio-economic indicators and the impact of paddy waste smoke on human health and the environment were also required. For example, information on human health during and after the period of burning, measures adopted by people in the vicinity to cope with the situation and other production, income and expenditure parameters, were not collected in the PPCB survey.

To obtain information on these matters, household surveys on health status and a number of socio-economic variables were undertaken May 2009 in the same three villages where PPCB conducted its 2006 investigation. To then combine the 2006 and 2009 data required the assumption that no significant change had occurred either in the incidence or volume of rice stubble burning or in the air pollutants emitted by burning. Consultation with the Punjab Department of Agriculture indicated that farming practices and rice varieties in this region had not changed significantly over the intervening period and hence that these were reasonable assumptions.

Selection of the survey households in the respective villages was based on stratified random sampling. Lists of all households including those who were cultivators, agricultural labourers and those who were working in the other formal or informal sectors were constructed. Stratification was done for the cultivating households in terms of marginal farmers ($\leq$1.0 hectares (2.5 acres)); small farmers (1.0 to 2.0 hectares (2.51 to 5.0 acres)), medium farmers (2.0 to 4.0 hectares (5.01 to 10.0 acres)) and large farmers (above 4 hectares (10.0 acres)). From each village, approximately 10 farm families were selected for each category. A total 40 farmers were selected from each village and 120 farmers overall. In addition to cultivating households, 10 landless labourer families were selected from each village. The aggregate survey sample therefore consisted of 150 households, from which 625 individual surveys were completed.

The survey sought detailed information on various aspects of inputs used by the farmers for agricultural practices, disposal of crop residues and socio-economic characteristics:

- individual household members' age, education, sex, occupation and marital status;
- end-use of stubble;
- current health status of individuals and symptoms of illnesses linked to air pollution, including incidence of any chronic disease;
- strategies followed by household members to mitigate the health effects of smoke exposure;
- general awareness amongst household members of illnesses that occur due to air pollution;
- agricultural productivity, input usage and stubble management;
- medical expenditure and workdays lost during the rice stubble burning period;
- expenditure on formal medication (such as fees paid to doctors) and cost of hospitalisation and expenditure on allopathic treatment and informal medicines that Indian households generally take without consulting a medical professional; and
- information on individual habits and households assets, including whether an individual was an habitual smoker, regularly drank alcohol or was taking any other toxicants that affect health in general.

2.1.4 Survey Results

2.1.4.1 Household and Farming Characteristics

The ratio of males to females in the households surveyed was approximately 55 to 45 per cent in all the three villages selected (Table 2.2), which is similar to the broader population in Punjab (Kumar and Kumar 2010). The proportion of the sample population of working age was 70 per cent. About 28 per cent of the surveyed household members were illiterate or educated only up to primary level, 64 per cent were educated up to secondary level and 7 per cent were educated above secondary level. 67 per cent household members were self-employed in farming, while 14 per cent were wage earners and 11 per cent were involved in formal or informal salaried work.

Table 2-2: Household characteristics in Dhanouri, Simro and Ajnauda Kalan, Punjab, May 2009

		Dhanori	Ajnauda Kalan	Simro	Average
Family size		5.6	5.5	5.9	5.7
Males	%	54.7	55.2	53.4	54.4
Working age (16-60)	%	71.2	67.9	71.0	70.0
Illiterate	%	27.0	29.2	28.4	28.2
Educated to secondary	%	66.7	62.8	63.9	64.4
Educated above secondary	%	6.5	8.0	7.8	7.4
Self-employed farming	%	67.4	67.0	67.9	67.5
Self-employed non-farming	%	10.0	11.3	1.9	7.5
Salaried or pensioner	%	2.2	11.3	17.9	10.9
Wage earners	%	20.7	10.3	12.3	14.2

The average size of farmholdings across the surveyed villages was around 2.9 hectares (7 acres), of which 2.2 hectares (5.4 acres) were irrigated (Table 2.3). On average, leased-in area was more than leased-out area, except in Ajnauda Kalan. The cropping intensity was two or more crops in a year among all the surveyed households, with rice and wheat dominant.

2.1.4.2 Effect of Crop Stubble Burning on Human Health

Air pollution may lead to illnesses like eye irritation, bronchitis, asthma etc., increasing individuals' disease mitigation expenses and also affecting working capacity. In addition, open burning in the field affects life of animals, birds and insects below and above the earth. Burning at times also causes poor visibility and increases the incidence of road accidents.

The household survey conducted in 2009 showed that paddy stubble burning led to air pollution and several health-related and other problems among the selected villages (Table 2.4). There was no conclusive evidence of smoke caused by stubble burning affecting the health or productivity of milk producing animals. On the other hand, a significant numbers of households indicated that smoke caused loss of vegetation in the field and also led to road accidents during the peak of burning in the months of October and November. To the question whether households were aware of harmful effects of residue burning, more than 90 per cent of households indicated 'yes', but almost none were taking any preventive measures to escape from air pollution related diseases before the beginning of the harvest season.

Table 2-3: Farm characteristics in Dhanouri, Simro and Ajnauda Kalan, Punjab, May 2009

		Dhanori	Ajnauda Kalan	Simro	Average or aggregate
Operated area	ha/ac	2.5/6.1	3.4/8.4	2.8/6.9	2.9/7.1
Leased-in area	ha/ac	1.7/4.1	1.8/4.5	1.3/3.3	1.6/4.0
Leased-out area	ha/ac	0.8/2.0	2.2/5.5	0.0/0.0	1.4/3.4
Irrigated area	ha/ac	1.9/4.7	2.5/6.1	2.1/5.2	2.2/5.4
Cropping intensity		2.0	2.0	2.2	2.1
Household members		117	380	152	649
Marginal farms		10	10	10	30
Small farms		11	10	10	31
Medium farms		13	10	15	38
Large farms		6	10	5	21

Table 2-4: Percentage of households experiencing problems due to smoke caused by crop stubble burning - Dhanouri, Simro and Ajnauda Kalan, Punjab, May 2009

Problem	Dhanori	Ajnauda Kalan	Simro	Average
Awareness of harmful effect of residue burning	87.50	92.50	95.83	92.19
Family taken preventive measures to escape from smoke disease	2.04	0.00	0.00	0.71
Smoke affected productivity of other working members (attendant)	0.00	4.17	0.00	1.37
Experienced decline in productivity of milk producing animal	6.00	0.00	2.04	2.68
Milk producing animal suffering from sickness	0.00	0.00	4.08	1.35
Loss of vegetation due to smoke	60.00	59.18	87.76	68.92
Observed road accident happening due to smoke	8.00	24.00	89.80	40.27

Irritation in eyes and congestion in the chest were the two major health problems for the majority of the household members (Figure 2.1 and Table 2.5). Respiratory allergy, asthma and bronchial problems were other smoke-related diseases which affected household members in the selected villages. Almost 50 per cent of the selected households indicated that their health related problems were aggravated during or shortly after the rice harvest when stubble burning was in full swing during the months of October, November and December. In the peak season, affected families had to consult a doctor or use some home medicine to get relief from irritation/itching in eyes, breathing problem and similar other smoke related problems. On an average, the affected members suffered at least half a month from such problems and had to spend ₹300 - 500 per household on medicine (Table 2.6). In addition there were a few examples where a family member had to be hospitalized for three to four days and additional expenditure was incurred.

Figure 2-1: Number of Patients Treated in the Village Dispensary - Ajnauda Kalan

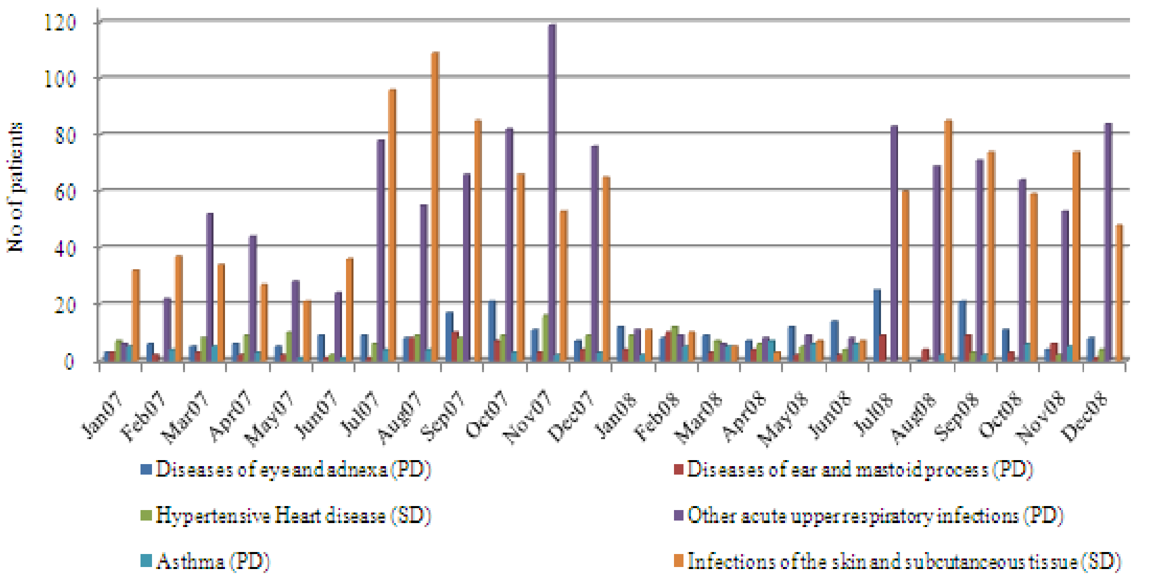

Table 2-5: Percentage of household members suffering from the disease due to crop stubble burning - Dhanouri, Simro and Ajnauda Kalan, Punjab, May 2009

Health Problem	Dhanori	Ajnauda Kalan	Simro	Average
Bronchial problems (inflammation of lungs due to infection or other causes)	1.56	2.04	0.00	1.14
Irritation in eyes (eyes feel as being burnt)	75.00	73.47	93.65	81.25
Coughing (congestion in the chest)	34.38	20.41	44.44	34.09
Experience nose/throat irritation due to smoke	4.32	0.00	0.68	1.65
Asthma (shortness of breath, chest congestion)	3.13	4.08	23.81	10.80
Emphysema (lung disease due to exposure to smoke, toxic chemicals etc)	0.00	0.00	0.00	0.00
Respiratory allergies (hay fever caused by stimuli like dust, smoke, air pollutants etc)	7.81	12.24	15.87	11.93
Other lung and heart disease	0.00	0.00	0.00	0.00
Any other health problem	3.13	8.16	1.59	3.98
Health problem gets aggravated during or shortly after crop stubble burning	52.00	52.00	42.55	48.98

Tables 2.6 and 2.7 present the total medical expenses incurred by households due to health problems during the crop stubble burning period. Family members suffering from smoke-related chronic and non-chronic diseases observed that their problem became acute and the severity increased during the time of crop stubble burning. On average, households spent more than ₹1,000 on non-chronic respiratory diseases, like coughing, difficulty in breathing, irregular heartbeat, itching in eyes decreased lung function etc., during the year 2008-09. Notably, out of this total expenditure, around 40 to 50 per cent was spent during the months of October and November

during the time of crop stubble burning. There was also an additional cost in terms of household members remaining absent from work due to illness.

Table 2-6: Expenditure incurred by households due to problems faced during the crop stubble burning - - Dhanouri, Simro and Ajnauda Kalan, Punjab

Problem	Unit	Dhanori	Ajnauda Kalan	Simro	Average
Family members visited local doctor during October-November, 2008	Average no of members per household (hh)	2.93	2.12	2.82	2.63
Prescribed any medicine during the main two months of stubble burning (Oct-Nov, 2008)	Average no of members per hh	2.93	2.15	2.82	2.64
	Avg no of days per hh	13.3	13.75	11.43	12.92
	Avg amount spent per hh (₹)	280.33	335.77	504.76	360.26
Any family member hospitalized during the main two months of stubble burning (Oct-Nov, 2008)	Average no of members per hh	0.00	1.00	3.00	2.00
	Avg no of days per hh	0.00	3.00	5.00	4.00
	Avg amount spent per hh (₹)	0	300	1000	650

Table 2-7: Medical expenses incurred by households due to health problems - Dhanouri, Simro ıd Ajnauda Kalan, Punjab

	Dhanori	Ajnauda Kalan	Simro	Average
Medical expenses incurred during the last year (Apr 08 to Mar 09)				
- Chronic disease (₹ per affected member)	1,667	1,750	2,000	1,750
- Non-chronic disease (₹ per affected member)	767	1,978	478	1,145
Percentage of affected members observing severity of problem increasing at the time of crop stubble burning	100.00	100.00	95.45	97.75
Medical expenses incurred due to acute problem during the crop stubble burning (Oct-Nov 08)				
- Doctor/hospital /other charges (₹ per affected member)	71	159	116	119
- Medicine cost (₹ per affected member)	162	222	200	196
- Transportation/freight (₹ per affected member	77	80	71	77
- Self-medication (₹ per affected member)	80	56	92	82
Absence from work for each illness during Oct-Nov 2008				
- No. of days per affected member	3	5	10	5
- Money loss (₹ per affected member)	300	600	1,000	610

2.1.5 Model Results

Due to data limitations, the economic costs associated with the negative health impacts of widespread rice stubble burning in Punjab were estimated only on the basis of the costs of medical and mitigation expenditure[14] and the opportunity cost of workdays lost. In undertaking this analysis, ambient air pollution was expressed in terms of particulate matter (PM_{10}) and SO_2 levels. Technical details of the methodology used and model results are provided in Appendix 1.

A positive and statistically significant (at 10 per cent level) association between ambient PM_{10} level and medical and mitigating expenditure was identified. This is strong evidence that individuals have to spend a higher amount of money to mitigate the adverse health effects when the particulate matter level is higher in the ambient environment.

The relationship between medical and mitigating expenditure and ambient SO_2 level is negative and statistically insignificant, contrary to expectations. This might be happening as the ambient SO_2 level is within the NAAQS limit in the villages of Punjab.

As expected, variables such as the smoking and drinking behaviour of the individual were found to also be statistically significant and positively related to medical and mitigating expenditure. These personal habits coupled with ambient air pollution make an individual more prone to asthmatic diseases and as a result they are required to spend more on medical treatment.

Similarly, we found a positive and significant relationship between the age of individuals and their medical and mitigating expenses, implying that these expenditures rise with age. We also observed a positive and statistically significant relationship between mitigating expenses and per capita assets. This might be happening because wealthier individuals do not hesitate to take mitigating action if they are susceptible to some diseases, in comparison to people who have lesser assets.

Education typically raises the awareness level of individuals with respect to environmental problems and related health damage and encourages informed preventative activities. However, this study did not identify a statistically significant relationship between mitigation expenditure and education level.

It was anticipated that individuals who have to work in fields where burning of agricultural residue takes place would be more prone to the adverse effects of pollution in comparison to their counterparts in other occupations, such as salaried individuals. The model was therefore designed to distinguish between farmers/agricultural wage earners and individuals in other occupations. As expected, a positive association between occupation and medical and mitigating expenditure was identified, confirming that individuals most directly exposed to the smoke do indeed face higher medical expenses. It is notable that more than 60 per cent of the population in Punjab live in rice growing areas (Singh *et al* 2008) and are hence directly exposed to air pollution due to the burning of rice stubbles.

It was also found that the probability of losing workdays due to illness increases as the concentration of particulate matters in the ambient environment increases. This effect lessened with the level of education, implying that education increases awareness levels and encourages effective preventative action thus helping to minimise workdays lost. Similarly, as wealthier individuals can spend money on preventing activities there was a negative relationship between per capita assets and workdays lost.

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[14] Medical and mitigating expenditure includes expenses incurred as a result of air pollution related diseases. These expenditures include costs of medicine (formal as well informal), doctor's fee, diagnostic tests, hospitalization, and travel to doctor's clinic during the two months of rice harvesting.

Based on the survey data and technical modelling, if the ambient PM_{10} level in rural Punjab was reduced from the level observed during the harvesting period of rice to the safe level (a reduction of 207 $\mu g/m^3$), the estimated reduction in medical expenditure was estimated to be ₹2.17 for the months of October and November for a representative person.

The total rural population projected for October 2008 based on Census 2001 is 1.083 million and 16.839 million for the district of Patiala and the state of Punjab, respectively. Extrapolating this welfare loss for the entire rural population of Patiala and Punjab, the increase in medical expenditure at these regional levels arising from rice stubble burning is estimated at ₹2.35 million and ₹36.52 million, respectively.

It was also estimated that a one $\mu g/m^3$ increase in PM_{10} results in a marginal loss of 0.0000946 work days for a representative individual in the harvesting months of October and November. If the PM_{10} level is reduced from the current level to the safe levels during this period, the estimated gain in workdays is 0.03 per individual. In monetary terms, the cost in terms of workdays lost for a representative individual is estimated to be ₹2.35, or ₹2.54 million for the total rural Patiala district and ₹39.57 million for rural Punjab in its entirety (assuming a wage rate of ₹120 per day).[15]

Hence, the total monetary loss (due to lost workdays and increased medical expenditures) caused in terms of health damages due to an increase in ambient PM_{10} level beyond the safe level for the rural areas of Patiala district and Punjab state is estimated as, ₹4.89 million and ₹76.09 million, respectively (Table 2.8).

These losses should be considered the lower bound of the health damages caused by the increased air pollution level in rural Punjab. The losses would be much higher if expenses on averting activities, productivity loss due to illness, monetary value of discomfort and utility could be counted and the economic cost of motor vehicle accidents caused by low visibility. There are of course, additional non-health related monetary costs of burning to the farmers in terms of additional fertilizer, pesticides and irrigation, and losses of soil nutrients, vegetation and bio-diversity.

Table 2-8: Estimated Welfare Losses Due to Increased Air Pollution in Rural Punjab

	Representative individual	Rural Patiala District	Total Rural Punjab
	(₹)	(₹ millions)	(₹ millions)
Medical Expenditure	2.17	2.35	36.52
Opportunity Cost of Workdays Lost	2.35	2.54	39.57
Total Welfare Loss	4.52	4.89	76.09

2.2 Review of Air Pollution Control Laws and Policies[16]

In this section of the report the existing suite of legislation in India and Punjab to control air pollution is described and policies and institutions established by the Punjab Government to address agricultural waste burning in particular are detailed.

[15] A wage rate fixed for the state of Punjab under National Rural Employment Guarantee Act (NREGA).
[16] This section is largely drawn from Kumar and Joshi (2010), which contains considerably more detail on the existing legislative settings.

2.2.1 Various Laws to Control Pollution in India

2.2.1.1 Air (Prevention and Control of Pollution) Act 1981

The Air (Prevention and Control of Pollution) Act 1981 or 'Air Act' was legislated to monitor the quality of air in India and to take measures for the control, prevention and abatement of air pollution. The Air Act, which applies to whole of India, came into force on 1 April 1988.

Air pollution is defined as the presence in the atmosphere of any solid, liquid or gaseous substance in such a concentration/proportion which may prove harmful to the health of human beings, animals and other living creatures and plants and environment.

Under the Act, the Central Pollution Control Board (CPCB) is given all necessary powers to ensure the prevention, control and abatement of air pollution. Each state is also required to establish a State Board with the necessary powers for the prevention and control of air pollution. The Central Board acts as the main board for the control and prevention of air pollution in Union territories.

The CPCB is responsible for informing the governments of union territories about the suitability of any location or premises for carrying out industrial activities or other activities which are likely to emit air pollutants in the atmosphere. The Central Board is also responsible for declaring air pollution control areas and setting standards for treatment of sewage and trade affluent and for emission from automobiles, industrial plants and any other polluting source. The CPCB has also to assess the quality of ambient water and air and inspect waste water installation, air pollution control equipment, industrial plants or manufacturing processes to evaluate their performance and to take steps for the prevention, control and abatement of pollution.

Under Section (16) of the Act the Central Board has the following functions:

- Advising the Central Government on any matter relating to the prevention, control and abatement of air pollution. The board is responsible for running nation-wide programmes for the purpose of ensuring control, prevention and abatement of air pollution.
- Coordinating with different State Boards, provide technical assistance and guidance, and conduct the necessary investigations and research to ensure adequate measures are being taken for air pollution control and also to resolve any disputes that may arise within the State Boards.
- Organising adequate training programmes for individuals who would engage in programmes for the control, prevention and abatement of air pollution.
- Organising nation-wide programmes for the prevention, control and abatement of air pollution.
- Establishing standards for the ambient quality of air.
- Collecting, compiling and publishing technical and statistical data relating to air pollution and highlighting measures for its effective prevention, control and abatement.
- Ensuring that any information on pollution related matters like air pollution level alerts etc., are disseminated regularly to people through media or other means.

Section (17) of the Act defines the functions of State Boards, such as the Punjab Pollution Control Board (PPCB), as follows:

- Advising state governments on all matters relating to the prevention, control and abatement of air pollution, and the feasibility of any location or premise from the emission of air pollutants point of view, for setting up an industry.

- Coordinating with the Central Board the public dissemination of pollution related information and training programmes for individuals involved in the control, abatement and prevention of air pollution.
- Setting standards for the emission of air pollutants into the atmosphere from industrial plants, automobiles or for the discharge of air pollutants from any other source.
- To ensure that all the functions are being carried out in a timely manner. Furthermore to ensure that any task towards air pollution control and abatement prescribed by the Central Board, state governments from time to time is carried out satisfactorily.

If a State Board fails or defaults in complying with directions give to it by the Central Board and an emergency situation has arisen because of it, then the Indian Government can give orders to the Central Board to perform any of the functions of the State Board in relation to the affected area.

State Boards have the power to inspect at any time, any industrial unit or manufacturing plant to ensure that the air quality standards are met and to take steps where ever necessary for the control, abatement and prevention of air pollution.

Under sub-section (1) of Section (19) of the Act, state governments have the power to declare any area within a state as pollution sensitive area, or air pollution control area after due consultation with the State Board. If the state government after due consultation with the State Board is of the opinion that any fuel is likely to cause air pollution in any air pollution control area, it may by notification in the official gazette prohibit the use of such fuel in such area with effect from such date as prescribed in the notification. Similarly if the state government after consultation with the State Board is of the opinion that the burning of any material apart from fuel is likely to cause emission of air pollutants in the air pollution control area, then it may by notification in the official gazette prohibit the burning of such material in such area. Any disputes/ inconsistencies between the Central and the State Boards in the discharge of their functions would be taken care by the Indian Government.

No person operating any industrial plant in a pollution control area may discharge or cause or permit to be discharged any air pollutant in excess of the standards laid down by the State Board. If a State Board finds that the emission of air pollutants is in excess of these standards, the State Board may make an application to the court restraining the emission of such air pollutants. Any person who fails to comply shall in respect of each failure be punishable with imprisonment of a minimum of one year and six months, but which may extend up to six years and with a fine. If the failure continues beyond one year of the initial conviction, the offender shall be punishable with an imprisonment of a minimum of two years, but which may extend to seven years with a fine.

Under Section (38) of the Act, a person who fails to inform the State Board, any officer or other employee about the occurrence of the emission of air pollutants in excess of the standards laid down by the State Board or about the expectation of such occurrence, may be liable for a penalty:

If any company or industrial unit is found guilty of violating the provisions of the Act, then as per Section (40) of the Act, every person in charge of and responsible for the conduct of business at the time the offence was committed, shall be deemed guilty of the offence and shall be liable to be punished accordingly (this includes the head of a government institution).

It would seem that to the extent that the burning of rice stubbles or other agricultural waste gave rise to gaseous or particulate matter emissions in excess of established standards, powers under this Act could potentially be used to limit the practice. However, there is some uncertainty around whether this Act can in fact be applied to agriculture and provide authority over farming practices.[17]

2.2.1.2 Environment (Protection) Act 1986

The main objective of the Environment (Protection) Act 1986 is the protection and improvement of the environment. Under section (3) of the Act, all necessary powers for the purpose of protecting and improving the quality of the environment and preventing, controlling and abating environment pollution are vested with the Indian Government. Environment pollution refers to the presence of any environmental pollutant in the atmosphere, where an environmental pollutant is defined as the presence of any solid, liquid or gaseous substance present in such concentration as may be or tend to be injurious to environment.

The following are considered to be the functions of the Central Government under the Act:

- Coordinating with various state governments, officers and other authorities under this Act on the rules made there under.
- Organising and planning nation-wide programmes for the prevention, control and abatement of environmental pollution
- Laying down standards for the quality of the environment for the prevention, control and abatement of pollution. This includes laying down standards for emissions from different sources to manage the discharge of environment pollutants.
- Providing guidelines on areas or regions where industrial operations cannot be carried out and if industrial operations do take place then to ensure that adequate precautions are taken to prevent environment pollution.
- Establishing procedures and safeguards for the prevention of accidents which may cause environment pollution.
- Laying down procedures and safeguards for the handling of hazardous substances.

Under Section (6) of this Act, the Central Government may make rules in respect for all or any of the following matters through notification in the Official Gazette:

- The air, soil and water quality standards for various areas and purposes.
- Maximum allowable limits of concentration of various environmental pollutants.
- The procedures and safeguards for handling of hazardous substances.
- Prohibition and restriction on the handling of hazardous substances.
- Prohibition and restrictions on the location of industries.
- Procedures and safeguards for the prevention of accidents which may cause environment pollution and providing remedial measures for such accidents.

The Act requires that no person carrying out any industry, operation or process shall discharge or emit or permitted to discharge any environment pollutant in excess of any prescribed standard.

Under section (11) of the Act, the Central Government or any of its officer empowered by it in this behalf, has the power to take samples of air, water, soil or any other substance from any of the factory, premises or any other place for the purpose of analysis.

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[17] Dr G.S. Kalkat, Chairman, Punjab State Farmers' Commission, and Dr P.K. Kaushal, Director, Punjab State Planning Board, are of the view that this Act does not apply to farmers, personal communication, October 2010.

It would seem that to the extent that the burning of rice stubbles or other agricultural waste gave rise to environment pollution, powers under this Act could potentially be used to limit the practice.

2.2.1.3 National Environment Appellate Authority Act 1997

The National Environment Appellate Authority Act 1997 was established with the objective of establishing an Authority for hearing appeals with respect to restrictions on the areas in which industries, operations or processes or classes of industries could be carried out.

The provisions of this Act would not be triggered in respect of rice residue burning except and unless powers under the Environment (Protection) Act 1986 were used to restrict the areas in which rice could be grown and/or the areas where stubble burning could be practised.

2.2.1.4 The National Environment Tribunal Act 1995

The National Environment Tribunal Act 1995 was constituted with the objective of providing strict liability arising out of any accident occurring in handling hazardous substances and for the establishment of a National Environment Tribunal for quick and effective disposal of cases arising from such accidents, with a view to giving relief and compensation for damages to any person, property and the environment.

Under Section (2) of the Act:

- 'accident' is defined as an accident involving a sudden or unexpected or unintended occurrence while handling any hazardous substance resulting in continuous or intermittent or repeated exposure to death of, or injury to, any person or damage to any property or environment; and
- 'hazardous substance' means any substance or preparation which is defined as hazardous substance in the Environment (Protection) Act 1986 and exceeding such quantity as specified by the Indian Government under the Public Liability Insurance Act 1991.

Deliberate and planned burning of rice stubbles or other agricultural waste would not come under the jurisdiction of this Act.

2.2.1.5 Biological Diversity Act 2002

The Biological Diversity Act 2002 has the objectives of conservation of biological diversity, sustainable use of its components, and fair and equitable sharing of the benefits arising out of the use of biological resources and knowledge. Under this Act:

- biological diversity means the variability among living organisms from all sources and ecological complexes of which they are part and includes diversity within species or between species and of ecosystems; and
- biological resources means plants, animals and microorganisms or parts thereof, their genetic material and by products (excluding value added products) with actual or potential use or value but does not include human genetic material.

The National Biodiversity Authority established by the Central Government under Section (8) of this Act, may:

- advise the Central Government on matters relating to the conservation of biodiversity, sustainable use of its components and equitable sharing of benefits arising out of the utilization of biological resources; and
- advise State Governments in the selection of areas of biodiversity importance.

Under the Act, state governments can establish respective State Biodiversity Boards. In the case of the Punjab, it is the Punjab Biodiversity Board. The functions of State Biodiversity Board are to advise their respective State government, subject to any guidelines issued by the Central Government, on matters relating to the conservation of biodiversity, sustainable use of its components and equitable sharing of the benefits arising out of the utilisation of biological resources.

Under Section (36) of the Act, the Central Government is required to develop national strategies, plans and programmes for the conservation, promotion and sustainable use of the biological diversity, including measures for identification and monitoring of areas rich in biological resources.

Wherever the Central Government feels that the biological diversity or biological resources of an area are being threatened by overuse, abuse or neglect, it can issue directives to the concerned State Government to take immediate corrective measures. The Central Government may also undertake measures to analyse the environmental impact of the project which is likely to have an adverse impact on the biological diversity, with a view to avoid or minimize such effects.

It is possible that powers under this Act could be used to constrain rice stubble burning if it was considered that this practice posed a threat to the biological diversity or biological resources of an area.

2.2.2 Existing Policies to Control Agriculture–Related Air Pollution in Punjab

The Punjab Pollution Control Board (PPCB) and the Punjab State Council for Science and Technology (PSCST) are the key government institutions vested with the task of controlling pollution in Punjab. It is mainly the PPCB in coordination with the Central Pollution Control Board that advises the government on pollution related matters. The PPCB is the main governing body in Punjab for ensuring that standards for ambient air quality are met.

2.2.2.1 Punjab Pollution Control Board (PPCB)

The Central Government's Air (Prevention and Control of Pollution) Act 1981 and the Environment (Protection) Act 1986 have been adopted by the Government of Punjab to control air and environmental pollution in Punjab. The Punjab Pollution Control Board (PPCB) abides by these Acts and is entrusted with the task of ensuring that they are being followed in Punjab.

The main objectives of the PPCB include effective control of air and water pollution, controlling pollution at source and ensuring that pollution control standards are met. The PPCB has the function of planning and implementing a comprehensive program for the prevention, control and abatement of pollution. PPCB supports and encourages developments in the field of pollution control, and ensures that the information collected by means of reports and projects on the pollution levels in various sectors is disseminated timely so that the Punjab Government can formulate policies accordingly.

The PPCB routinely monitors pollution levels at 20 locations, of which nine are in residential cum commercial areas and 11 are in industrial areas.

2.2.2.2 Punjab State Council for Science and Technology (PSCST)

The role of the Punjab State Council for Science and Technology (PSCST) is to harness the potential of science and technology as instruments of socio-economic change in Punjab. The Council provides technical support to the Punjab Government for development through science and technology. One of the Council's key 'thrust' areas is pollution control and within that broader issue, specifically addressing the problem of agricultural waste burning.

In September 2006, the PSCST constituted a Rice Stubble Pollution Control Task Force under the chairmanship of its Executive Director in September 2006 to consider the problem of agricultural waste burning. The Task Force found that there is a need to adopt new ways and methods for better utilisation of agriculture waste, especially rice stubble, to mitigate the problem of the pollution caused by burning these residues in the field.

The 2006 State Environment Punjab report prepared by the Council reported that the burning of crop stubble had been banned in the State. It seems, however, that while this was a strongly favoured position a legal order to this effect may never have been formally made. It is certainly the case that no legal action has ever been taken against farmers to enforce any such ban, and there is a consistent view across government agencies in Punjab that it would be unfair to ban rice stubble burning unless and until there are economic alternatives for farmers.[18]

In addition to the formal roles of the above agencies, a further broad array of initiatives have been undertaken by other departments/ institutions in Punjab which act to directly or indirectly reduce agriculture waste burning and hence the associated air pollution.

2.2.2.3 Punjab Department of Agriculture

In recent years it has been increasingly felt by the Punjab Government that it would be desirable to at least partially adjust farmers away from rice-wheat crop rotation into new areas like vegetables, fruits, oil seeds, pulses, etc (Kumar and Joshi 2010). Crop diversification is an important strategy to protect both the natural resource base and stabilise farm income.[19]

The Punjab Government in 2002 launched a multi-crop multi-year contract farming scheme to give a boost to crop diversification. The Punjab Agro Food Corporation (PAFC) has been implementing the task and it is believed that more than 0.186 million acres is now under crops other than wheat and paddy (eg., hyola, winter maize, sunflower, durum wheat, moong), with around 100,000 farmers under the program (Punjab Food Corporation 2005). Further, the Department of Agriculture is promoting diversification of cropping pattern in Punjab under which area under Basmati rice, from which the stubble can be used as a fodder, had increased from 150,000 hectares to 350,000 hectares in the past five years (Kumar and Joshi 2010).

Other initiatives of the Department of Agriculture to reduce the level of stubble burning include training farmers in the benefits of alternative practices such as reincorporation of crop residues, protein enrichment of paddy/wheat stubble through urea treatment, use of stubble as animal bedding and zero-till production systems. The Department has also demonstrated and subsidised the supply of rotavators, Happy Seeders, zero–till-drills and stubble reapers. As a result of these programs, the area under zero tillage in Punjab increased from 6,830 hectares in 2001-02 to 412,690 hectares in 2005-06.

2.2.2.4 Agriculture Councils

As noted above, in the past few years the Punjab Government has been encouraging diversification in agriculture, away from the rice-wheat cropping pattern towards other remunerative and less water intensive crops. In 2005-06 ₹100 million was budgeted for the creation of an 'Agricultural Diversification, Research and Development Fund'. The funds are being used for the development of better quality of alternative agricultural crops, improved agricultural practices and improved post harvesting management practices. In order to encourage farmers to use crop stubble as fodder for

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[18] Dr N.S. Tiwana, Executive Director, Punjab State Council for Science & Technology, and Dr B. Ram, Member Secretary, Punjab Pollution Control Board, personal communication, September 2008.

[19] The Punjab State Planning Board (Mr P. Kaushal, Director, personal communication, September 2008) and Punjab State Farmer's Commission (Dr G.S. Kalkat, Chairman, personal communication, September 2008) have also been promoting crop diversification for some years.

animals and to meet fodder requirements during the scarcity period, ₹2 million of the Fund was set aside for enrichment of stubble and cellulose waste.

To intensify its diversification programme in the agriculture sector, in 2006 the Punjab Government set up four Special Purpose Vehicles (SPVs) to promote citrus and fruit juices, value-added horticulture, viticulture and organic farming. These are:

- Council for Citrus and Agri. Juicing
- Council for Value added Horticulture
- Organic Farming Council of Punjab
- Viticulture Council of Punjab

The main objective of these Councils is to take measures for shifting Punjab from primary agricultural and low value produce to high value processed products. The Government's aim is that one-third of the State's farm sector should diversify to citrus and high value horticulture, viticulture and organic farming in the next ten years. The new strategy lays emphasis on production of fruits and vegetables under controlled conditions, using modern practices like net houses, plastic tunnels and green houses (Kumar and Joshi 2010).

In addition to the above, ₹505.6 million was provided in the Annual Plan of 2006-07 to strengthen agricultural infrastructure and speed up the process of agricultural diversification in the state. In the Annual Plan 2006-07, a new programme, 'Agriculture Production Pattern Adjustment Programme in Punjab for Productivity and Growth' under the 12th Finance Commission was included with a budgetary provision of ₹240 million per annum for the four years to 2010.

2.2.2.5 Punjab Energy Development Agency (PEDA)

The Punjab Energy Development Agency (PEDA) has also been investigating the potential to use agricultural waste, such as rice stubble, as a source of fuel for electricity generation. Successful development of this technology would provide at least some farmers with an economic alternative to stubble burning.[20]

PEDA has been facilitating the establishment of 29 power projects with a total installed capacity of 330 MW on BOO basis to private developers. The plants are designed to receive mixed waste such as paddy stubble, cotton stalks and other agro residues available in Punjab. An 8 MW project was commissioned in March 2009 and another of 14.5 MW in September 2009.

2.2.2.6 Punjab Agricultural University (PAU)

Punjab Agricultural University (PAU) had been according priority towards developing efficient agro-technologies for crop residue recycling in machine harvested areas as an alternative to burning. The major pieces of equipment developed by PAU includes the Happy Seeder machine, Tractor Operated Paddy Stubble Chopper and Stubble Collector and Baler (Kumar and Joshi 2010).

PAU has also been working on incorporation of crop residues in the soil and the use of rice stubble as bedding material for animals and thereafter for composting.

2.2.2.7 Punjab State Farmers' Commission

In order to reduce area under paddy without decreasing the income of the farmers, the Punjab State Farmers' Commission has initiated the following programmes:

[20] The Department of Rural Development is popularising technologies proposed by the Department of Agriculture and PEDA and is facilitating provision of panchayati land for setting up of biomass based power plants in Punjab.

- commercial dairy farming and increasing the area under fodder;
- production of vegetables under net house technology;
- encouraging cultivation of hybrid maize in the Kharif season; and
- introduction of new high value crops, such as bananas.

2.2.3 Conclusions

The survey and economic evaluation conducted in this study show a clear increase in medical and health-related expenditure and work days lost during the rice stubble burning period (September – November) each year. These health-related expenditures tend to be higher for older people and the more wealthy and workers, such as farmers and farm labourers, and rural dwellers who are most directly exposed to rice stubble burning. In this regard, it is notable that 60 per cent of the population in Punjab live in rice growing areas and are hence directly exposed to stubble smoke.

The total health-related economic cost (combining both lost workdays and increased medical expenditures) of rice stubble burning in the rural areas of Punjab state is estimated at ₹76.09 million annually. This estimate does not include expenses on averting activities, productivity loss due to illness, or the direct and indirect costs of motor vehicle accidents caused by low visibility, and is hence very much a lower bound estimate.

In recognition of these health-related costs and the undesirable farm productivity and environmental consequences of stubble burning, substantial government funding and research and extension effort has been invested in initiatives to reduce this practice. In addition, it is understood that the Punjab Government regularly publishes the adverse impacts of crop stubble burning in local newspapers, and that these papers frequently contain articles requesting farmers to stop burning stubble or creating awareness among them about its ill effects (Kumar and Joshi 2010). While these various initiatives have had some effect, the vast majority of the rice stubble produced in Punjab is still burned in the field.

While it appears that legal power to limit or even totally ban stubble burning exists under statutes such as the Air (Prevention and Control of Pollution) Act 1981 and the Environment Protection Act 1986, these powers have not been exercised. It is clear that there is a consistent view across government agencies in Punjab that it would be unfair to ban rice stubble burning unless and until there are economic alternatives for farmers.

Subsidised adoption of the Happy Seeder technology has been part of the government response, and consideration has been given to increasing the level of subsidy to promote increased adoption. Elsewhere in this report, the potential to encourage Happy Seeder adoption and/or desirable crop diversification (i.e., land-use change) through change to other policy settings is explored.

3. RESIDUE MANAGEMENT IN THE NORTH-WEST INDIA RICE-WHEAT PRODUCTION SYSTEM

The 2009 survey conducted in the Patiala district of Punjab described in section 2 of this report found that in the case of paddy residues, more than 85 per cent was burnt in the open field, less than 10 per cent was incorporated and the small remaining proportion was used for other purposes (Kumar and Kumar 2010). In contrast, in the case of wheat, 77 per cent of the stubble produced was used as fodder for animals, while 9 per cent was incorporated and only around 11 per cent was burnt.

The main reasons given for burning paddy stubble in the open field were (i) that burning was more economical (48 per cent of respondents), (ii) the shortage of time between harvesting of paddy crop and sowing of wheat crop (41 per cent), and (iii) non availability of a machine which could be used to collect the crop remains after the combine harvest. A rotavator[21] was used by around 10 per cent of the households to incorporate rice residues after combine harvest, but it could be used only after partly or fully burning the field. According to 82 per cent of the farmers surveyed, the easiest and quickest way of paddy stubble removal was burning: not only were the majority of farmers of this opinion, they were also convinced that this method of stubble management was ensuing them the maximum crop yield.

As already observed, it is believed that in aggregate around 80-90 per cent of the estimated 17 million tonnes of rice stubble produced in Punjab each year is burnt in the field. As may be expected, there is considerable interest in finding alternative uses of these stubbles, not only to avoid the private and social costs of disposal but, and more importantly, to change them from a waste product to an economically valuable output of the farming system.

In a previous ACIAR project PLIA/2006/180 'Happy Seeder Policy Linkage Scoping Study', it was found that rice residues may have the potential to be used in:

- thermal power plants as fuel for electricity generation;
- bio-gasification in electricity generation;
- ethanol production;
- livestock feed;
- cushioning material in the packaging of manufactured goods;
- paper and plywood;
- floor tiles;
- mushroom production; and
- soil conditioning using improved residue incorporation technologies.

Kumar and Joshi (2010) identified a similar list:

- fodder for animals;
- bedding material for animals

[21] A rotavator, also known as a rototiller, rotary hoe, power tiller, or rotary plough, is a motorised cultivator that works the soil by means of rotating tines or blades. Rotavators are either self-propelled or drawn as an attachment behind a two or four-wheel tractor.

- generation of electricity;
- mushroom cultivation;
- paper production; and
- making bio-gas.

Picking up on this issue, the ACIAR project LWR/2008/014 'Review of Alternative Rice Residue Use and Management Technologies in Punjab' organised a stakeholder workshop, hosted by the Punjab State Farmers Commission at Chandigarh on 1 October 2009. This workshop brought together leading scientists, farmers and policy makers to consider the current and prospective technical feasibility of alternative use options for rice stubble. Presentations from the workshop were compiled into a set of workshop proceedings (Singh and Crean 2010).

In summary the workshop found that while a number of off-farm prospective uses may well become economic and generate some demand for rice stubble into the future, even in aggregate they are unlikely to consume more than around ten per cent of the volume generated in Punjab each year (Singh and Crean 2010). Taken together with evidence that possible on-farm uses for rice residues, such as for stock feed or livestock bedding, are out-competed by wheat stubbles, it is easy to understand why these residues are simply considered a waste to be disposed of as quickly and easily as possible.

Furthermore, given that rice stubbles have no economic value to the farmer, any management solutions that do not involve disposing of them must provide benefits to the farmer that at least outweigh any additional costs incurred. Otherwise there is no incentive for change. This report presents evidence that direct drill technology with the capacity to handle heavy stubble loads, such as the Happy Seeder, meets this condition and offers an effective, practical solution.

4. EVALUATION OF POLICY OPTIONS TO REDUCE AGRICULTURAL AIR POLLUTION

4.1 Policy Environment of Agriculture in North-West India

The incentive to invest in a Happy Seeder machine (either through purchase or a lease arrangement) depends upon both the on-farm production economics of the technology and the influence of external signals, such as culture and government programs and regulation. Farmers in Punjab have a reputation for being business-minded and prepared to innovate on the basis of demonstrated sound economics. This is evidenced by the profound change in commodity selection and production approach in Punjab in response to the incentives provided through the Green Revolution and subsequent government programs.

As outlined previously (see section 1.1), the institutional framework for agriculture in India includes:

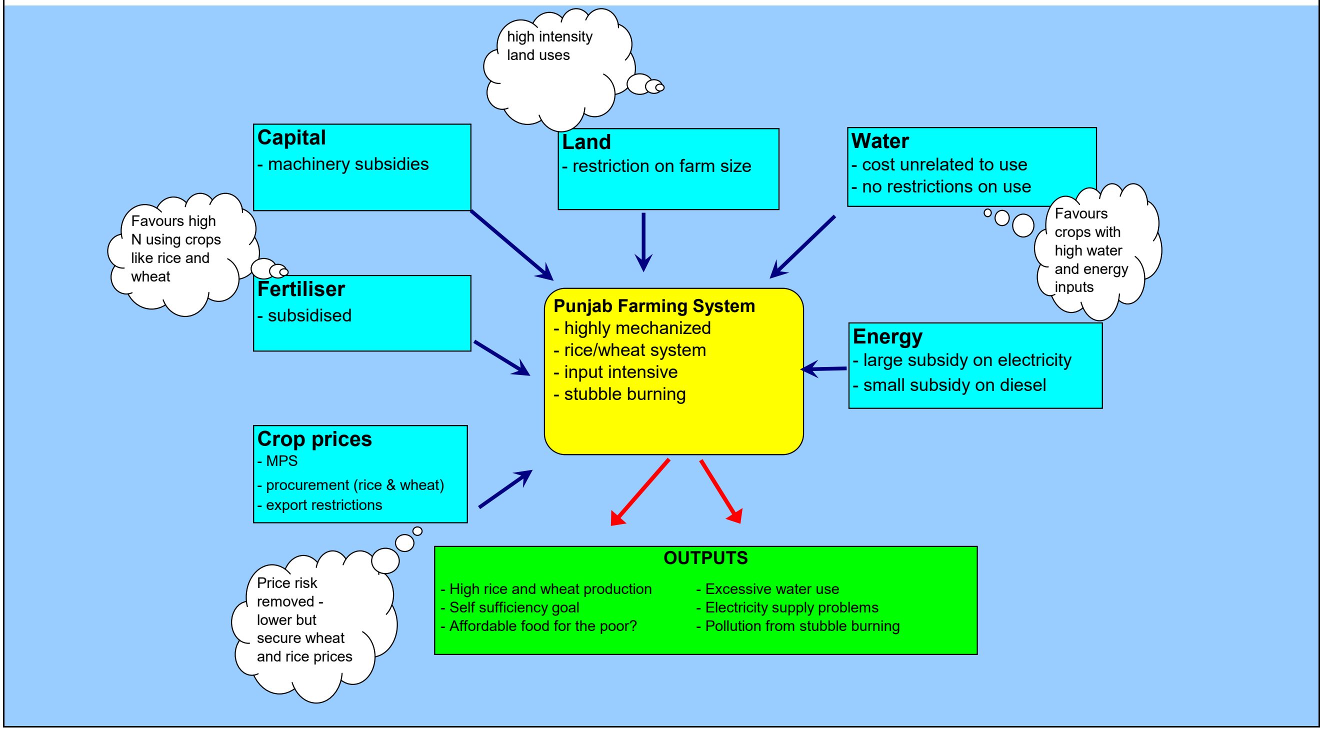
- authority for the central and state governments to regulate and control production, distribution and pricing of commodities considered essential for consumers;
- regulation of the establishment of markets and marketing of agricultural produce at the state level to ensure that all trade between farmers and initial buyers goes through a regulated market;
- minimum support prices on 'essential' commodities, with rice and wheat prices supported by government procurement and buffer stocks; and
- budgetary support for inputs (fertilisers, water, electricity and seeds) and infrastructure (irrigation, water supply, roads and electrification) (OECD 2009).

It is apparent that government policy and programs at the State and national level since the 1960's have in fact significantly influenced farmers' decisions in Punjab and led to the farming system now prevalent in that state (summarised in Figure 4.1). That is, the existence of an intensive rice-wheat farming system in Punjab that generates large amounts of rice stubbles that are then burnt in the field is in fact largely a function of government policy settings. This is an important point to appreciate in the context of considering actions that could be taken by government to encourage uptake of alternatives to rice stubble burning.

As outlined in section 1.2, the Happy Seeder is designed to allow direct planting of a wheat crop into fields with heavy rice stubble loads. This provides production, environmental and social benefits:

> *The HS approach has considerable potential agronomic benefits, in addition to reducing air pollution and retention of nutrients and organic matter, by avoiding stubble burning. The mulch suppresses weeds and may reduce the need for weed control measures, and reduces soil evaporation (Sidhu et al. 2007, 2008; Yadvinder-Singh et al. 2008). Wheat can be sown immediately after rice harvest, while the stubble is still too green to burn. Traditionally, a pre sowing irrigation is applied prior to sowing wheat after rice. This irrigation may not be required with the HS where there is quick turn around before the residual surface soil moisture from the rice crop is lost by soil evaporation.* (Singh *et al*. 2008, p3)

Figure 4-1: Influence of Government Programs on Farming in Punjab



While the decision for a farmer to invest in a Happy Seeder will depend firstly on the direct benefits exceeding the cost, this is not a sufficient condition. An equally important factor is for these net benefits to exceed the perceived net benefits of alternative investments. That is, the opportunity cost of a Happy Seeder must also be lower than that of alternative investments. This seems to not be the case for the Happy Seeder: of the several thousand items of farm equipment distributed to farmers on subsidy by the Punjab Department of Agriculture only relatively few have been Happy Seeders.

4.2 Modelling the North-West India Rice-Wheat Production System

4.2.1 Description of the optimisation model

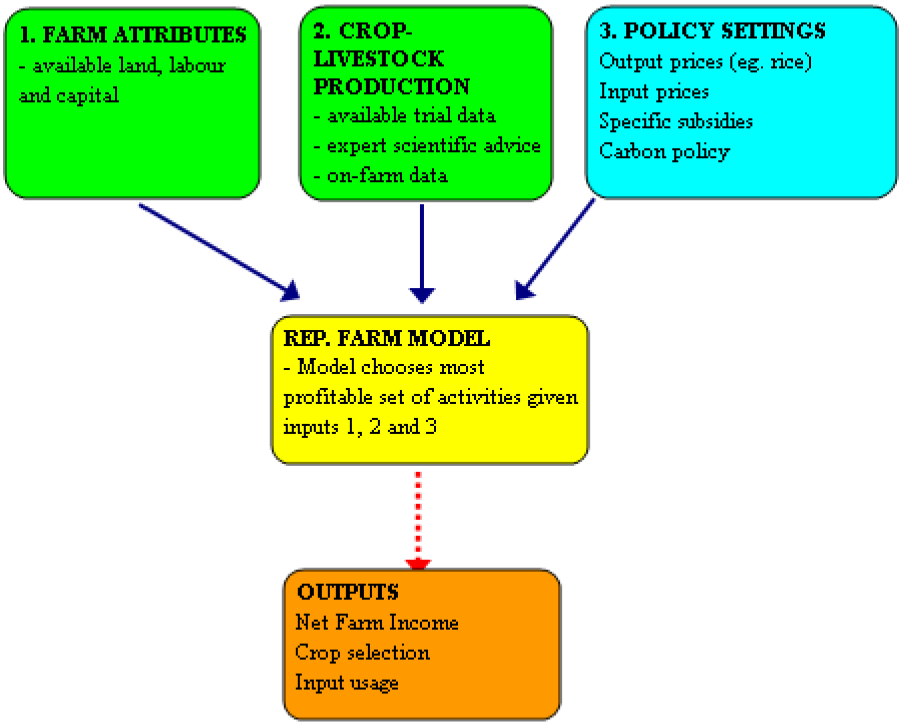
To assess the influence of policy settings on land use and technology adoption in Punjab a farm level model of agriculture in Punjab was developed. The model attempts to represent the key physical and economic characteristics of small-scale farming in Punjab. The farm level model is of a linear programming (LP) form and adheres to the general farm planning maximisation problem, where an objective function is maximised through the choice of an optimal set of activities, subject to a number of physical constraints (see Figure 4.2). LP has been extensively applied to a wide range of agricultural issues and is one of the most widely used optimisation techniques.[22]

Linear programming was considered to have particular advantages in this study. There are many ways in which policy settings in India can influence land use, various options for policy change and many complexities associated with the double cropping farming system adopted in Punjab. Under these conditions it is difficult to fully consider the possible interactions between various policy settings and land use in the absence of a formal model. A significant constraint on the adoption of

[22] A well formulated LP model offers a number of advantages over more simplified spreadsheet-based analyses. There are also, however, a range of well-documented deficiencies of LP methods (see Hardaker 1971; Dent *et al.* 1986) including an assumption of linearity, perfect divisibility and an objective function which maximises profit (in this case) where other objectives might also be equally applicable. Dent *et al.* (1986), Pannell (1997) and others suggest that many of these problems can be minimised with a little thought and ingenuity.

alternative investigation methods was the limited availability of empirical data, owing to the fact that many of the potential policy settings have never been implemented.

Figure 4-2: Farm Economic Model



The Punjab farm level LP model is set up as a standard farm planning maximisation problem of the following form:

$$\text{Max} \quad Y = \sum_{j=1}^{n} c_j x_j \qquad (1)$$

Subject to:

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i \qquad (i = 1 \text{ to } m) \qquad (2)$$

and:

$$x_j \geq 0 \qquad (j = 1 \text{ to n}) \qquad (3)$$

where Y is the objective function to be maximised, c_j are the objective function values for the decision variables, x_j are the decision variables, a_{ij} are the input-output coefficients and b_i are the resource constraints. In a typical farm planning problem, the objective is to find the farm plan (represented by decision variables x_j) that leads to the highest level of net farm income Y, but which does not exceed the fixed resources of the farm or permit negative activity levels (Hazell and Norton 1986). Each of these elements is now described in the context of the representative farm model of Punjab agriculture.

The objective function of the Punjab LP model assumes that the farmer's aim is to maximise net farm income (Y) by selecting the optimal mix of crop and livestock activities (x_j) subject to constraints on land, labour, capital and water (b_i). Policy settings associated with inputs of

electricity, water, fertiliser and machinery (including the Happy Seeder technology) were introduced either through changes in the objective function values (c_j) or by changes to resource constraints (b_i). Policy settings concerning the pricing of outputs (eg., minimum support payments for rice and wheat) were also reflected directly in the assumed objective function values.
There are approximately 250 activities (x_j) represented in the model. These are comprised of: alternative crop activities (rice, wheat, maize, soybean, mungbeans) under different water application rates (low, average, high), irrigation layouts (flood irrigated and raised beds) and establishment methods (conventional, direct seeding, Happy Seeder technology for wheat); pasture activities (summer, winter and opportunity pasture); and livestock activities (cows, buffaloes and bullocks). Separate annual activities were introduced to cover the sale of grain and alternative uses of stubble (on-farm livestock use, sale, burn) and the purchase or hire of some inputs (nitrogen fertiliser, permanent labour, machinery). Monthly activities were also included to cater for within-season labour, irrigation water demands, pasture and fodder transfers and purchases, and on-farm milk production and household consumption.

The model parameters were specified to reflect a typical rice-wheat farm in Punjab (Table 4.1). The farm draws water from groundwater supplies in order to irrigate predominantly rice and wheat crops grown in rotation. The central and state governments provide free electricity to farms for this purpose. However, the high demand placed on electricity supply at key times results in power outages and restrictions in access to the otherwise free electricity. At these times, farmers revert to the use of their much more expensive diesel pumps. Although the model includes constraints on monthly water availability, these constraints are set to non-binding levels to reflect the current situation of unmetered access. Access to water is assumed to be only limited by pump size, although there has been a long term downward trend in groundwater levels in the region which may necessitate some form of restriction in the future. No prices are placed on the water resource itself so the marginal cost of using water from a farmer's perspective relates directly to the operating costs of pumps. A major component of this cost relates to energy use, which in the case of electricity is provided free of charge.

Table 4-1: Punjab representative farm model parameters

Attribute	**Value**
Farm Area	4.40 hectares
Crop Area	4.20 hectares
Cropping Season	Summer, Winter
Crop and livestock activities	rice, wheat, mungbeans, maize, soybeans
Water source	groundwater only (unrestricted access and unpriced)
Irrigation infrastructure	7.5HP electrical pump, 5HP diesel pump
Electricity access	Jun-Jul - 5hrs/day, Apr-Aug - 6hrs/day, Remainder - 8hrs/day
Labour	Owner/operator, family, 1 permanent, casual

The main focus of the modelling was to understand the importance of policy settings in influencing land use, the use of inputs and the adoption of new technologies. With this in mind, some of the key inputs required for cropping activities (eg., water, electricity, fertiliser) were identified separately to facilitate an assessment of changes to policy settings. Base information on the input-output coefficients (grain and stubble yields, irrigation requirements, rotational effects associated with weeds, disease and nitrogen status etc) associated with each cropping activity were based on Dhaliwal *et al.* (2006) and Singh *et al.* (2006). Input prices and output prices were based on 2005-06 data. These input costs and market prices reflect current policy settings which provide significant subsidies on electricity, water, fertiliser and machinery inputs, whilst also guaranteeing prices for rice and wheat through the government's procurement program. Parameters concerned with the specification of the Happy Seeder technology were based on Singh *et al.* (2006). Initial applications of the model were presented at the Australian Agricultural and Resource Economics Society Conference in Melbourne (see Milham, Crean and Singh 2011) and the 5th World Congress of Conservation Agriculture in Brisbane (see Milham *et al* 2011).

4.3 Alternative Policy Scenarios

The policy settings varied for the purposes of this study related to:

- **Electricity prices** - while electricity is currently free for farmers in Punjab, a search of the literature (eg., Fan *et al*. 2007) suggested that if Indian farmers paid the same cost for electricity as other industrial consumers then this would equate to a price of around 3.60 rupees per kilowatt hour. This value was used as an estimate of the electricity price that farmers in Punjab might be expected to pay in an unsubsidised market. An alternative policy setting tested involved removing the subsidy and exposing the farm to the full cost of the electricity used;

- **Fertiliser prices** – a subsidy currently exists on the costs of nitrogen fertiliser. An estimate of the size of the subsidy was calculated at 2.14 rupees per kilogram of nitrogen. This was calculated by simply dividing the total subsidy paid to the Indian fertiliser industry in 2008/09 by the tonnes of fertiliser produced in the same year. In some policy scenarios analysed, this subsidy was removed;

- **Happy Seeder cost** – farmers can avail themselves of the Happy Seeder technology by outright purchase, shared purchase with one or more other farmers or by hiring a contractor. The option used in this analysis was that of hiring a contractor, but with the contractor passing on any savings made possible by the government subsidy on the purchase cost of Happy Seeder. The alternative policy settings tested involved varying the level of subsidy on the purchase between 0 and 45 per cent. The current level of subsidy on private capital purchase on Happy Seeder in Punjab is 35 per cent; and

- **Air pollution/emissions tax** - a tax on stubble burning was introduced based on internalising to farm businesses the approximate health costs arising from the smoke they produce. The size of the tax was varied to investigate the level of impost required to trigger a switch in behaviour given average stubble loads. In a similar fashion, a carbon price was also introduced on GHG emissions generated by stubble burning.

A further scenario considered the longer term economic benefits that technologies like the Happy Seeder could provide by creating an opportunity to produce an additional, short duration, crop such as mungbeans, between the wheat and rice rotations.

4.4 Policy Assessment Framework

The problem that confronts government and industry in north-west India is a rice-wheat farming system that produces a large amount of anchored rice residue for which there is currently minimal on- or off-farm economic use and which is easy to burn at minimal cost. In addition, food security remains a key public policy objective and the main cause for heavy involvement of the government in regulating the agriculture sector. The policy is intended to *"ensure adequate supplies of food staples at remunerative prices for farmers, and to provide food at stable and affordable prices to consumers"* (OECD 2009, p99). The challenge is thus to find solutions that reduce pollution without reducing food production or increasing production costs in a way that significantly impacts consumer prices.

In principle, the policy alternatives in these circumstances range from the provision of information to farmers on strategies that could be adopted or changing incentives to stimulate change to the farming system (i.e., encouraging a shift to production systems that produce less anchored stubble and/or consume more of the stubble produced) to directly restricting air pollution. Without seeking to be exhaustive, the array of interventions could thus include:

- information and extension campaigns on the deleterious on- and off-farm impacts of stubble burning, together with the conduct of relevant research;
- reducing incentives that have favoured rice production and the selection of rice varieties with high yields of residues of comparatively low value as stockfood;
- support for on-farm management of stubble (eg., through subsidised harvesting and preparation as a stockfeed or payments for stubble incorporation as a carbon sequestration or water-use efficiency measure)[23];
- support for off-farm uses of stubble (eg., through subsidised harvesting and/or transport costs);
- taxing air pollution; and
- an enforced prohibition on stubble burning, associated with fines or other regulatory penalties for air pollution.

Given the broad array of policy alternatives, a consequent issue is to establish a framework for assessing their relative merits and choosing between them. In determining the principles that should apply to this issue, reference can appropriately be made to the concept of market failure (see Box 1) and the principles of competition embodied in OECD micro-economic reform principles.

Box 1: Forms of Market Failure

- *Imperfect competition* is characterised by unequal bargaining power between market participants. The misuse of market power may result in inefficient resource allocation.
- *Externalities* and *spillovers* are benefits or costs associated with the activities of an individual or business which are imposed on others. The existence of externalities indicates that market participants are either not reaping the full rewards or are not bearing the full costs of their actions. Consequently, there may be too few or too many resources devoted to the activity in question.
- *Public goods* are goods, which because they cannot be withheld from one individual without withholding them from all, must be supplied communally. Because there are no property rights for them, they are free to be utilised by anyone as and when desired. These conditions tend to lead to under-investment in these goods. Agricultural R&D, for example, often produces public goods.
- *Imperfect or asymmetric information* is where market participants are not equally or fully informed. This may lead to decisions by market participants that are not in their own best interests and/or the best interests of the general community.

[23] Development and subsidised adoption of direct-drill technology such as the Happy Seeder would also fit into this category.

Micro-economic reform as it relates to agricultural policy has been a focus of both developed and developing economies for many decades, with market failure principles now becoming generally accepted in guiding efficient policy reform processes. It is an accepted principle of modern democratic government that *"it should come in and interfere with citizens' freedom* [which includes the functioning of markets] *only where there is a clear case to do so"* (Wilkins 2006). It is also accepted that competitive, freely operating, markets will provide the most efficient allocation of resources within an economy.
The presumption is that over time competitive markets will generally deliver greater net benefits than restricted markets. It is thus fundamental in market-based, or competition, policy that government intervention should not be considered unless a market failure problem has been identified. This, of course, requires a basis upon which to make a judgement be made that market failure is occurring, i.e., that the current use of a defined set of resources is not delivering maximum value to the community.

In a democratic, market-based, economy like India, a measure of whether or not maximum community benefit is being obtained is the extent to which public policy objectives are being achieved. From this, provided objectives have been clearly and measurably defined, market failure can be readily identified as the situation where the freely operating market fails to deliver desired public policy outcomes.

If the unfettered market is not delivering the socially desired outcome, or there is significant risk that this will be the case, there is a *prima facie* case for considering government intervention. Where the desired outcome is being achieved without government intervention, however, application of the market failure principle would lead to the conclusion that, as there is no need, government should not intervene in the market. Furthermore, if the market is failing but it is not possible for government action to effectively address the problem, or the costs of feasible interventions are higher than the benefits, intervention would again be inappropriate. The concept of market failure thus provides an objective and consistent basis for determining when it is necessary and appropriate for government to take direct action to achieve outcomes that are considered desirable by the general community. Where there is market failure, the preferred policy instrument is then that which achieves the policy objective and maximises the net benefits from intervention while least restricting competition (Wilkins 2006).

The OECD Positive Reform Agenda (OECD 2002) thus calls for governments to be clear about what their policy objectives are and to define them in a measurable way that lends itself to the assessment of market failure and alternative policy instruments. This in turn increases transparency and reduces the influence of politics in decision making. There is significant concern, however, in relation to the ability of countries to apply these principles and the approach. While the merits of market based policy approaches are now well accepted, the ongoing prevalence of poor agricultural policy settings reflects the common necessity to manage strong 'rent seeking' behaviour by sectoral and political interests. These situations necessarily have their solution in the underpinning incentive systems at play, which may overvalue short-term income and political benefits relative to the longer term viability of agriculture and the costs imposed on others and the environment.

A useful perspective on this is provided by White (2008) where 'industrial policy' is portrayed as often standing in juxtaposition with competition (or trade practices) law. The author highlights that most countries traditionally have sectoral policies (such as regulated commodity prices and input subsidies) designed to influence resource allocation, with broadly stated objectives relating to growth and productivity outcomes.

In relation to agriculture, the tension between industrial policy, which is considered to often be about 'rent seeking' and income redistribution, and competition policy is highlighted by agriculture often being formally exempt from anti-trust laws. This tension extends to the adverse effects that poorly developed industrial policy has on providing competitive advantage to certain agricultural businesses and outputs and the often unforseen effects that regulatory incentives may have in causing producers to become locked in to certain production patterns. It is readily apparent that the situation the Happy Seeder has been designed to address could be defined in these terms.

This is not to deny, however, that industrial policy has an important role where it legitimately targets instances of market failure that would not otherwise be expected to be addressed by market-based approaches and competition policy (eg., food security, environmental externalities and information asymmetry problems).

In summary, the principles applied to the assessment of potential alternative policy or program responses in this study were:

- that they should be clearly focussed on addressing the mischief being cured (air pollution and other environmental and social costs of rice stubble burning), and if possible should harness private interest to achieve this goal;
- that they should as closely as possibly represent minimum intervention, market-based solutions and hence be consistent with OECD micro-economic reform principles;
- that they should reflect an understanding of the broad economic, social and historical context in which the rice-wheat farming system in Punjab has its origins; and
- that they should not act to entrench other policies or programs that provide counterproductive incentives.

4.5 Modelling Results

As described above, the modelling approach exposed the representative farm model to alternative policy settings to examine the subsequent response in the optimal farm plan and resultant outcomes for key variables including landuse (i.e., the area under various crops), the use of key inputs of water, electricity and diesel, agricultural productions levels, farm incomes and the adoption of the Happy Seeder.

4.5.1 Scenario 1: Market Pricing of Electricity and Fertiliser

The first scenario tested current conditions, incorporating current subsidies, against a new set of policy conditions where electricity and fertiliser were fully priced. The model was optimised under these alternative policy settings, with the set of enterprise options constrained to those most commonly observed on farms in Punjab (wheat, rice and maize). Results from the analysis are presented in Table 4.2.

Under current policy settings, involving the provision of subsidies on fertiliser and electricity, but with no assistance for the purchase of Happy Seeder, the optimal farm system has the following characteristics:

- the entire productive area of the farm (4.20 hectares) is allocated to rice in the summer and wheat in the winter;
- net farm income is about ₹173,000 per year;
- the farm consumes around 97 megalitres of water, 530 kilograms of nitrogen and 8,700 kilowatt hours of electricity;
- the management system involves conventionally sown rice which is mechanically harvested and remaining stubble burnt prior to the establishment of the next wheat crop; and

- around 30 tonnes of rice stubble is burnt with related emissions of 1.38 tonnes of CO2-e[24].

Table 4-2: Modelled effects – with and without subsidies (restricted crop choice)

	With Subsidies	Without Subsidies
CROP MIX		
Rice (ha)		
- conventional sown (RW)	4.20	3.93
- zero till (RW)	0.00	0.00
Wheat (ha)		
- conventional sown (RW)	0.00	0.00
- zero till (RW)	4.20	0.00
- Happy Seeder (RW)	0.00	3.93
- conventional sown (MW)	0.00	0.27
Maize (ha)	0.00	0.27
Soybean (ha)	0.00	0.00
CROP PRODUCTION		
Rice (t)	29.40	27.49
Wheat (t)	23.63	23.63
Maize (t)	0.00	1.37
Mungbean (t)	0.00	0.00
RESOURCE USE		
Rice stubble burned[25] (t)	29.40	0.00
Emissions (t of CO2-e)	1.38	0.00
Nitrogen (kg)	533	439
Electricity (kw hrs)	8,670	0
Diesel (L)	19	483
Water (ML)	97	89
INCOME		
Net farm income (₹)	172,605	149,291

Note: Total farm area 4.40 hectares; total cropped area 4.20 hectares.
RW- rice-wheat rotation, MW- maize-wheat rotation

When the policy settings are altered so that production costs reflect the true value of electricity and fertiliser, the following model responses are observed:

- the area of rice declines from 4.20 to 3.93 hectares and a small area (0.27 hectares) of maize is grown in its place;

[24] Calculated through the application of the algorithms contained in the Australian National Greenhouse Accounts – specifically equations 4F_1 to 4F_3, section 4F "Field Burning of Agricultural Residues" (Department of Climate Change and Energy Efficiency, 2012).

[25] The quantity of stubble burnt depends on the stubble to grain ratio. Based on data reported in

- the total area of wheat remains the same at 4.20 hectares, although the 3.93 hectares grown in rotation with rice is now established using the Happy Seeder;
- the savings in irrigation and fertiliser associated with stubble retention make Happy Seeder the preferred option for all wheat establishment without the provision of subsidies. As a consequence, no rice stubble is burnt and there are no related CO-2 emissions;
- the pricing of electricity is particularly significant at ₹3.60 per kilowatt hour. This places a value on the water resource and is a major driver of the adoption of Happy Seeder;
- removing subsidies on electricity leads to the use of diesel to extract irrigation water. Overall water use fell by 8 per cent from 97 to 89 megalitres; and
- although net farm income falls to around ₹149,000 (-14%), the farm remains profitable.

4.5.2 Scenario 2: Market Pricing of Electricity and Fertiliser with Cropping Flexibility

Scenario 2 involves the same policy settings as Scenario 1, but with flexibility to broaden the traditional farming system beyond those crops widely practised to those that might become feasible. A significant additional benefit of direct drill technologies, such as the Happy Seeder, is time savings that create the potential for a further short-duration crop to be grown (Rajinder Singh, pers. comm., 2010).

The results shown in Table 4.3 include the possibility of growing a third crop, namely mungbeans, between the wheat and rice crops. Naturally, this is found to substantially improve the economics of direct drill technology such as the Happy Seeder over conventional farming[26] because it adds further income and provides rotational benefits through improvements in soil condition and the biological fixation of nitrogen.

The main observations that can be made from Table 4.3 are as follows:

- In the 'with subsidies' case:
  - the full crop area of 4.20 hectares is planted to a rotation of conventionally sown rice, followed by wheat (established with Happy Seeder) and mungbeans;
  - the introduction of mungbeans, made possible through the use of Happy Seeder, improves the relative profitability of the whole rice-wheat rotation; and
  - relative to the 'with subsidies' case of scenario 1, the farming system improves in profitability (by 9 per cent) to around ₹189,000, requires less purchased nitrogen, and avoids the burning of rice stubbles.
- In the 'without subsidies' case:
  - the crop mix remains unchanged, with 4.20 hectares planted to a rotation of conventionally sown rice, followed by wheat (established with Happy Seeder) and mungbeans;
  - farm profitability falls to around ₹163,000, but the place of rice is maintained in the farm system; and
  - the removal of subsidies on electricity leads to the use of diesel pumps to extract irrigation water but overall water use remains the same.

[26] Direct drilling wheat after burning rice stubble may also open up the option of a third crop, so this benefit is not unique to the Happy Seeder, however, only the Happy Seeder provides additional public benefits of rice stubbles not being burned.

The key point to note from Scenario 2 is that the optimum production mix, even with current subsidies, includes use of the Happy Seeder and thereby eliminates residue burning. The improved profitability of the whole system, made possible by a third crop, makes the use of Happy Seeder privately profitable, irrespective of government policy settings.

Table 4-3: Modelled effects – with and without subsidies (flexibility over crop choice)

	With Subsidies	Without Subsidies
CROP MIX		
Rice (ha)		
- conventional sown (RW)	4.20	4.20
- zero till (RW)	0.00	0.00
Wheat (ha)		
- conventional sown (RW)	0.00	0.00
- zero till (RW)	0.00	0.00
- Happy Seeder (RW)	4.20	4.20
- conventional sown (MW)	0.00	0.00
Maize (ha)	0.00	0.00
Soybean (ha)	0.00	0.00
Mungbean (ha) – third crop	4.20	4.20
CROP PRODUCTION		
Rice (t)	29.40	29.40
Wheat (t)	23.63	23.63
Maize (t)	0.00	0.00
Mungbean (t)	4.33	4.33
RESOURCE USE		
Rice stubble burned (t)	0	0
Emissions (t of CO2-e)	0	0
Nitrogen (kg)	432	432
Electricity (kw hrs)	8,670	0
Diesel (L)	19	548
Water (ML)	101	101
INCOME		
Net farm income (₹)	188,644	163,362

Note: Total farm area 4.40 hectares; total cropped area 4.20 hectares.
RW- rice-wheat rotation, MW- maize-wheat rotation

Based on these results, an alternative investment to the provision of subsidies on Happy Seeder would be further research and development into additional management practices or crop varieties to realise the opportunities for the planting of a third crop. Given the rotational benefits mentioned above, this might also address some concerns about the longer term sustainability of intensive rice-wheat production systems.

4.5.3 Scenario 3: Subsiding Purchase of the Happy Seeder

One objective of this project was to investigate whether adoption of the Happy Seeder technology would be enhanced by increasing the level of government subsidy available to farmers purchasing the machine. Financial assessments of Happy Seeder undertaken by Singh *et a*l (2011) have concluded that the technology is already financially viable for farmers, and is more profitable than available alternatives, particularly conventional tillage. Intuitively, if this was widely perceived to be the case, there would be limited value in looking at the effect of a subsidy to further improve the profitability of its use.

Nevertheless previous assessments of Happy Seeder have noted some limitations with respect to data availability. One concern has been the limited number of farms evaluated, meaning that the findings of the financial analysis may not be broadly applicable to all farms. A second concern has been the reliance on contract rates (assumed for many other farm operations as well), rather than costs reflecting machinery ownership, as a basis for analysis. This has also been a consideration in the development of the representative model used here and is discussed below.

Subsidies on capital cost have the largest influence on technology costs if the technology has large up-front costs and is used infrequently. High up front capital costs and low levels of utilisation both work in the direction of having high capital costs per hectare of use. Subsidies under these conditions can make a large difference to the size of these costs and hence provide significant on-farm incentives for adoption. There are of course questions about the economic merit of the public subsidising the capital cost of private assets, particularly those that will be used only infrequently.

The utilisation of a Happy Seeder machine would be very low if individual farmers purchased it for their sole use. In terms of work rates, it takes around 3.75 hours to plant one hectare of wheat using the Happy Seeder. In the case of our representative farm, with a maximum crop area of 4.20 hectares, on-farm the use of the Happy Seeder would equate to just 15.75 hours or around 2 days per year. This represents just 7.5 per cent of the wheat sowing window of around 30 days. With such a low level of direct utilisation, there are obvious opportunities for the excess capacity of the Happy Seeder technology to be contracted out.

The following analysis is based around the Happy Seeder becoming available to farmers through contract arrangements rather than outright purchase. This seems the most likely way in which the majority of farmers would actually access the technology. The main parameters used in the analysis are contained in Table 4.4.

Table 4-4: Assumptions for calculation of the Happy Seeder contract rate

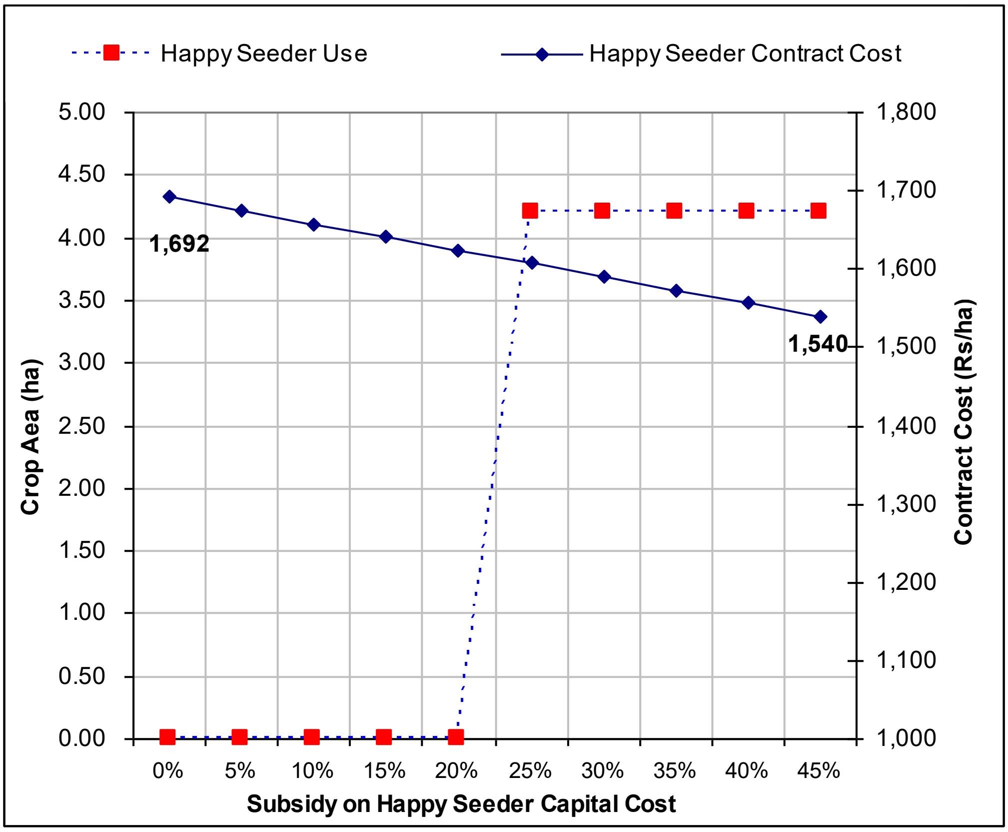
Category	Value
Capital cost	₹135,000
Asset life	10 years
Subsidy	0, 5%, ……..45%
Interest rate	10% per annum
Depreciation	Straight line (salvage value of 2%)
Repairs and maintenance	2.5% of unsubsidised capital cost/year
Assumed use	60 ha (30 days) – full utilisation
Happy Seeder only cost/ha (without subsidy)	₹392
Tractor operating costs/ha	₹1,300
Contract rate (without subsidy)	**₹1,692**

Contract costs have been calculated under different subsidy levels on the initial purchase price of Happy Seeder (estimated at ₹135,000). The level of subsidy influences contracting costs by lowering the amount paid for interest and depreciation. The subsidy does not influence other costs like repairs and maintenance and tractor operating costs (fuel, oil, tyres etc).

A scenario was constructed in which the representative farm model was provided the option of contracting Happy Seeder. The contract rate (i.e., the hire fee charged by the contractor) declined in line with the provision of a capital subsidy, which was varied from 0 to 45 per cent in 5 per cent increments. The level of subsidy at which the optimal farm plan switched away from conventional farming practices to use of the direct drill Happy Seeder technology indicates the point at which this would be an economic choice.

This scenario was tested with other policy parameters (i.e., fertiliser and electricity subsidies) set at their current levels and the mix of crops being restricted to those most commonly observed (i.e., without mungbeans). The results of the analysis are illustrated in Figure 4.3.

Figure 4-3: Impact of a Subsidy on the Capital Purchase of Happy Seeder



It was found that even a large subsidy has only a moderate effect on the contract rate. This was due to the significance in total costs of tractor operating costs, combined with the spreading of fixed costs (i.e., Happy Seeder purchase costs) over a larger area. The no-subsidy scenario delivered a contract rate of ₹1,692, while a 45 per cent subsidy reduced the contract rate by ₹152, to ₹1,540. The results indicate that a subsidy of just 25 per cent should be sufficient to encourage adoption of Happy Seeder. This is a lower subsidy level than the 35 per cent currently in place, however, when the analysis had been conducted very little adoption had been observed. Some reasons for this are explored in Section 4.6.

Further model simulations indicated that the economic merits of Happy Seeder use are very sensitive to even slight changes in key parameters. For example, even a 2 per cent improvement in the yield of wheat established with Happy Seeder was sufficient for the technology to be included in the optimal farm plan, without any subsidy at all on the capital cost of the technology.

This parallels earlier work of Singh *et al* (2010), who found that a 5 per cent improvement in wheat yield doubled the net benefits of Happy Seeder use over conventional tillage methods. If such yield improvements can be confirmed on farmer's fields, the technology may not require government subsidies to promote adoption as it will be profitable in its own right. An extension program to address information deficiencies, rather than a subsidy program, would clearly be a preferred option in these circumstances.

4.5.4 Scenario 4: Pollution tax and emissions pricing

The major problem being addressed in this research concerns pollution arising from the practice of stubble burning. Although subsidising the adoption of the Happy Seeder is a potential means to solve this issue, alternative options related directly to the practice of stubble burning also warrant consideration. In this section we address two options. First, we introduce a tax directly on the quantity of stubble burnt, with the tax set to reflect the costs of the adverse health impacts of local pollution. Second, we introduce a price on CO2-e emissions, reflecting regional/global concerns about climate change and India's own stance on reducing carbon pollution. These two policy settings are assessed in terms of their effect on the adoption of Happy Seeder as the most cost effective option to avoid stubble burning.

At a local or regional level, the burning of rice stubbles causes air pollution, with adverse effects on human health and increased road based injuries/ fatalities from reduced visibility. Section 2 quantified some of these adverse effects in Punjab, namely the costs of medical and mitigation expenditure and the opportunity cost of workdays lost, at around ₹76.09 million annually. An estimate of an average health cost of ₹4.97 per tonne of stubble burnt can be derived by applying this cost pro-rata to the total quantity of stubble burnt each year.

In theory, this cost could be passed onto farmers either in the form of a tax, an application of the 'polluter-pays principle', or as a subsidy to farmers to avoid stubble burning, an application of the 'beneficiary-pays principle'[27]. The same on-farm incentive exists in either case and it is introduced here as a tax that farmers pay on the quantity of stubble burnt.

The health tax applies to the amount of stubble actually burnt and was varied from ₹50-500 per tonne ($US 1-10). The results are reported in panel A of Figure 4.4. With current policy settings in place (free electricity and subsidised fertiliser), imposing an estimated health cost of ₹4.97 per tonne was not sufficient to trigger the adoption of Happy Seeder. In fact, a threefold increase in the estimated health cost to around ₹14.00 per tonne was required for this to occur. With around 30 tonnes of stubble being burnt under the base case, this would equate to an annual tax on the farm of just ₹420.

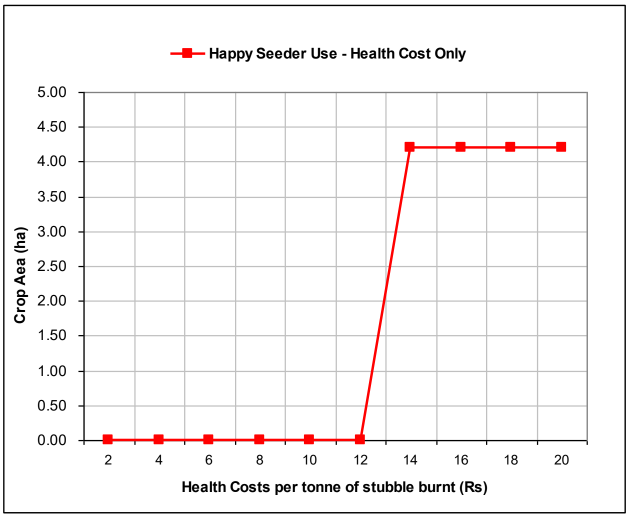
As noted above, burning rice stubbles also contributes to global warming through increasing greenhouse gas emissions (GHG). An assessment of emissions arising from stubble burning was also assessed based on emission factors contained in the Australian National Greenhouse Accounts (Department of Climate Change and Energy Efficiency 2012). On this basis, emissions were estimated at 0.051921 tonnes of CO2-e per tonne of stubble burnt and were comprised of methane (0.029714 tonnes) and nitrous oxide emissions (0.022207 tonnes). Applying a carbon price to these

[27] The Polluter-Pays Principle requires that those who impose a cost or a negative externality on others pay to alleviate and manage the problem in proportion to their contribution. The Beneficiary Pays Principle on the other hand implies that anyone who derives an indirect or intangible benefit from an activity should contribute to its cost.

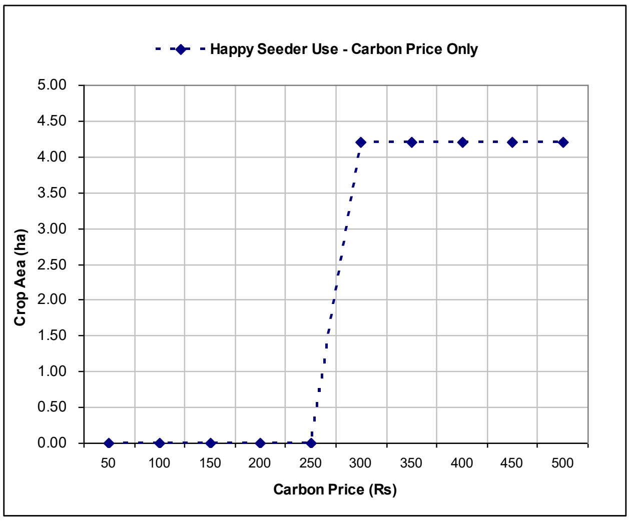
emissions creates a direct incentive to reduce stubble burning. Consistent with the treatment of health costs, the same incentive exists irrespective of whether farmers are paid a price to avoid emissions (additional income) or pay a charge on current emissions (additional costs). In this instance we introduce it into the model as a payment to farmers, which also accommodates the potential role of agriculture as a supplier of offsets to sectors with emission obligations.

Figure 4-4: Effects of health tax and carbon price on Happy Seeder use

Panel A: Health cost tax



Panel B: Carbon Price



A carbon price was introduced to reflect CO-2 emissions from stubble burning. It was varied from ₹50-500/tonne of CO2-e (US$1-10/t). As per the results in Panel B, a carbon price of ₹250/tonne (US$5/t) was sufficient to encourage the adoption of Happy Seeder. If this option was to become part of an agricultural offsets scheme, presuming that India commits to a national emission reduction target, then this would result in farmers receiving additional income at the same time as reducing local pollution effects arising from stubble burning. A significant benefit from this option is that such an offsets scheme gives flexibility to farmers to adopt the most efficient way of reducing stubble burning, and hence CO2-e emissions. Happy Seeder is the option modelled here, but such a policy measure leaves the decision open to farmers about the most suitable technology or practice available.

4.6 Policy Implications and Recommendations

4.6.1 Insights from the adoption literature

Like agricultural technologies more generally, the adoption of Happy Seeder can be considered by either looking at the attributes of adopters (ie. farmers) or attributes of the innovation itself. Lindner (1987, p. 146) reviewed empirical studies related to the adoption and diffusion of technologies and classified them broadly as:

Type A: Adoption studies (concerned with adopter attributes):

i) cross sectional (why some producers adopt an innovation while others don't?)
ii) temporal (why some producers are early adopters while others are laggards?)

Type B: Diffusion studies (concerned with innovation attributes)

i) cross-sectional (i.e., why are some innovations widely adopted while others are not?)
ii) Temporal (why do some innovations diffuse more quickly than others?)

Adoption-based studies take into considerations like the attributes of farmers (age, education, skills and attitudes), firms (farm size), social system (social mores) and the economic system (availability of credit, labour supply etc). Lindner observes that cross sectional adoption studies have been found to have generally low levels of explanatory and often provide contradictory findings about the importance of any given explanatory variable.

Diffusion studies, with a focus on attributes of the innovation, have proven to provide more insights. According to Rogers (2003), the five key attributes of an innovation can be used to explain between 49 to 87 per cent of the variance in the adoption of innovations. The five attributes are defined below based on Rogers (2003) and include relative advantage, compatibility, complexity, trialability and observability:

- *Relative advantage* - the degree to which an innovation is perceived as being better than the idea it supersedes. Relative advantage is often associated with some improvement in a measure of economic profitability. We prefer to think of it as the extent to which an innovation improves the welfare of the adopter which incorporates aspects of profit and risk and the opportunity cost of resources like family labour.
- *Compatibility* - the degree to which an innovation is perceived as consistent with existing values, past experiences and needs. Compatibility can be viewed as the extent to which an innovation is consistent with existing knowledge and practices within a given farming system. Innovations which are more compatible with the current system may be viewed as less uncertain to the potential adopter and are more likely to be adopted.
- *Complexity* - the degree to which an innovation is viewed as relatively difficult to understand and use. The relevance and application of some agricultural innovations will be relatively clear to farmers whilst other innovations may not be. The degree of an innovation's complexity is negatively related to its likely adoption.
- *Trialability* - the extent to which an innovation can be implemented on a limited basis. Some agricultural innovations (eg. a new wheat variety) are divisible in the sense that they can be adopted on a smaller scale prior to full implementation. Marra et al (2003) review risk and uncertainty aspects associated with the adoption of new agricultural technologies and highlight the important role that trialling of innovations has in reducing such uncertainty.
- *Observability* - the extent to which the outcomes of an agricultural innovation are visible to others. Clearly, innovations which are more readily observed allow for a greater flow of information to the adopter and other potential adopters about the performance of the innovation.

In this project we have focussed on the attributes of the innovation rather than on the attributes of adopters. More specifically, our attention has been towards policy settings which might either influence the rate or final extent of adoption of Happy Seeder by way of their effect on the relative advantage of the technology. Such a focus is consistent with Lindner who observed 'The finding that the rate of adoption as well as ultimate adoption level are determined primarily by the actual benefits of adoption to the potential adopters is by far and away the most important result to be culled from the empirical literature on adoption and diffusion' (1987, p. 150).

4.6.2 Policy settings to encourage adoption of Happy Seeder

Historical government policy settings have heavily influenced adjustment in the agriculture sector in Punjab. While these policies have for many years delivered on objectives relating to expanded production of key food crops, such as rice and wheat, and price stabilisation for consumers, there are strong and increasing concerns about sustainability of the farming system that has been created.

Using economic modelling at a farm scale and focussing on the specific case of the Happy Seeder, we have demonstrated that many of these policy settings act to limit the on-farm gains from adoption of improved production technologies. The economic analysis indicates the strong masking effects of electricity and fertiliser subsidies on the potential on-farm, environmental and public health benefits of the Happy Seeder technology.

Although options such as enhancing the government subsidy on the Happy Seeder could be considered as a mechanism to encourage increased adoption, reform of broader policy settings is a preferred economic policy approach. In our analysis we find that exposure to unsubsidised market prices for electricity and fertiliser, while marginally effecting rice production, would increase the attractiveness of technology such as the Happy Seeder and likely encourage adjustment to a farming system that is only marginally less profitable, generates less air pollution and uses less fertiliser, fossil fuel and water inputs. These changes are also likely to bring benefits to other sectors of the economy in terms of improvements in water availability and the reliability of electricity supplies.

Substantial reform aimed at addressing some of the current deficiencies in agricultural policy settings is challenging at best. Nevertheless, some prospective changes would actually reflect a return to policy settings previously in place. Indeed, electric pump sets were metered when they were first introduced in Punjab and farmers paid a charge based on the volume pumped. This policy was not changed until 1984, when flat rate charges were introduced, and then 1997, when electricity was made free to farmers. This subsidy was discontinued in 2002 and then reinstated in 2005 (Birner *et al* 2007). Hence, reintroduction of marginal cost pricing of electricity for farmers would represent a return to a relatively recent previous policy approach.

Financial assessments of Happy Seeder undertaken by Singh et al (2008) have concluded that the technology is already financially viable for farmers, and is more profitable than available alternatives, particularly conventional tillage. Although the economic modelling reported above supports this finding, it also notes that returns from the technology are very sensitive to even slight variations in yield parameters. To address this issue, consideration should be given to expanding the demonstration of the technology to other sites to address uncertainties about the extent of benefits. One aspect of the Happy Seeder technology that also warrants further investigation is the improved timeliness of operations which may allow the introduction of a third crop (eg., mungbeans) to the rice-wheat farming system. If direct subsidies are to play a role, then they could be used selectively and temporarily as a catalyst for adoption to raise awareness of the benefits of the technology.

Consideration has also been given to policy options which directly address the practice of stubble burning. In particular, if an agricultural offsets scheme was to develop as part of India's mitigation policy, farmers may actually receive additional income at the same time as reducing local pollution effects arising from stubble burning. A significant benefit from this option is that such an offsets scheme gives flexibility to farmers to adopt the most efficient way of reducing stubble burning. Happy Seeder is the option modelled here and is an effective solution, but such a policy measure leaves the decision open to farmers about the most suitable technology or practice available to them. Indeed, developments of an on offset market itself would provide incentives for further innovation in conservation agriculture equipment which might draw on important design breakthroughs achieved through the development of the Happy Seeder technology.

5. RICE STUBBLE MANAGEMENT IN AUSTRALIA

5.1 Policy Environment

Stubble burning in NSW, Australia is not prohibited and is in fact quite a common practice. The much smaller area of rice, combined with much lower population density where rice is grown, does not impose the same health concerns as those experienced in the densely populated areas of Northern India. There are however, some regulatory requirements that must be met before stubbles can be burned as discussed below.

The *Protection of the Environment Operations Act 1997* and associated *Protection of the Environment Operations (Clean Air) Regulation 2010* impose constraints on burning in relation to ensuring air pollution does not reach unacceptable levels. Extracts of relevant sections of these legislative instruments are contained in Appendix 2. The Act and Regulation impose a general obligation to prevent and minimise air pollution and provide that the NSW Environment Protection Authority can place a temporary ban on specified types of burning and in specified places if it is deemed that conditions are such burning would contribute to an unacceptably high level of air pollution. An approval under this legislation is not required to burn stubble.

The *Rural Fires Act 1997* imposes constraints on burning designed to ensure protection of the community from wild fires. Relevant extracts of this Act are in Appendix 2. The Act imposes a general duty on the owner or occupier of land to take steps to prevent the occurrence of bush fires on, and to minimise the danger of the spread of bush fires on or from, that land. More specifically, a person may not burn stubble in circumstances in which doing so would be likely to be dangerous to any building. Nor may they do so unless a bush fire hazard reduction certificate has been issued. Also, if the burn is proposed to take place during a bush fire danger period, which would not normally be the case, a fire permit is required.

5.2 Rice Production and Stubble Management in Australia

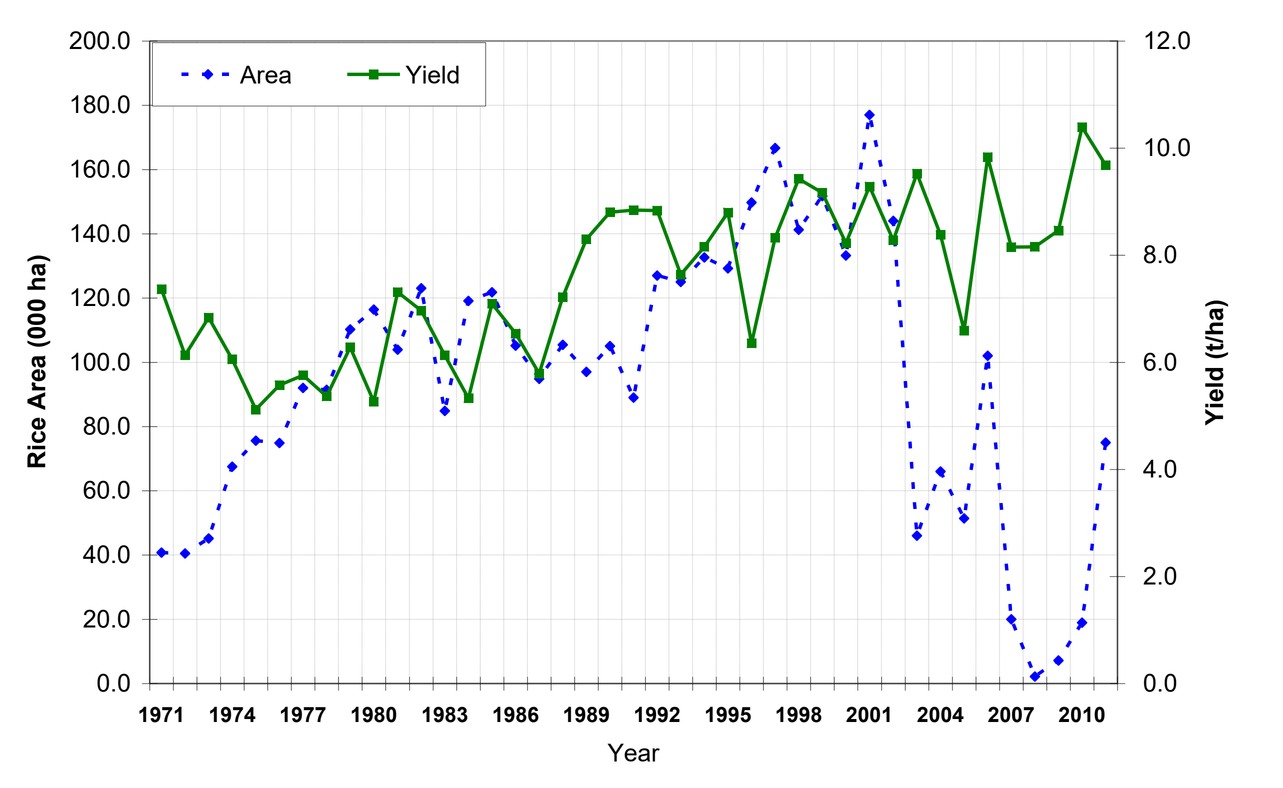
5.2.1 Rice Production

Rice is one of the most important summer crops in southern NSW, Australia. It is grown in rotation with winter cereals and/or annual and perennial pastures. The total area of rice increased substantially from the 1970's (Figure 5.1). The area sown peaked in 2001 with around 180,000 hectares. In 2001 the production of rice had expanded to $357 million and the industry was generating more than $500 million from value added exports annually (Rice Growers Association of Australia 2002). More recently crop areas have been adversely affected by substantial shortages in irrigation water arising from prolonged dry conditions in western NSW from 2002 to 2010.

Around 510,000 hectares of land is used for rice-based rotations (rice, winter cereals and pastures) with between 40,000 to 180,000 ha planted to rice each year. The main rice production areas include the Murrumbidgee Irrigation Area (MIA), Coleambally Irrigation Area (CIA) and the Murray Valley (MV) (Singh *et al*. 2003). NSW typically produces more than 95 per cent of Australia's rice crop. Policy changes to the allocation of water in the Murray Darling Basin, combined with the projected effects of climate change, suggest that is unlikely that the area of rice grown will exceed 125,000 hectares annually in the future (personal communication, Brian Dunn and Geoff Beecher, Yanco).

In southern NSW the average rice yield in recent years has been around 9-10 tonnes per hectare (Figure 5.1). Yields in this order have associated heavy loads of stubble (11-13 tonnes per hectare) and root biomass (5-6 tonnes per hectare) remaining in the field after harvest. High yields are also obtained in irrigated wheat production. Average wheat yields are around 5-7 tonnes per hectare with stubble loads of the same magnitude. Both rice and wheat stubbles are of relatively poor quality compared to other available hay or fodders options so there is generally limited interest in on-farm use or an off-farm market for these stubbles.

Figure 5-1: Australian rice area and yield



Australia is currently undertaking research into the use of rice stubble for compost, manufacturing particle board and stubble-bale buildings. In the absence of regular on or off-farm uses for rice stubble, most farmers burn the stubble before sowing the next crop. Even with strengthened fodder markets during the drought it is estimated that only 10-20 per cent of rice producers were able to bale and sell both rice and wheat residues, while another 10-20 per cent grazed these stubbles with sheep.

After rice harvest, high levels of moisture remain in the heavy clay soils. Many farmers utilise this moisture by direct drilling a cereal crop, normally wheat, soon after the rice has been harvested. Due to the unavailability of commercial machinery capable of direct drilling wheat in such heavy standing or mulched stubbles, most farmers direct drill wheat after complete burning of rice stubbles. Some farmers direct drill wheat after flag burning (partial burning) of stubble, especially under drought conditions when the stubble load is less than normal.

5.2.2 Rice Stubble Management

In Australia, it is estimated that rice-cereals based rotation farming system leaves behind a total of around 2.4 million tonnes of stubble (rice and winter cereals combined), of which over 90 per cent is burned each year. Burning of stubbles, which primarily occurs during April and May, results in significant loss of soil nutrients present both in rice and winter cereal residues (Table 5.1).

Burning of crop stubble (rice and wheat) also releases some gases harmful to human health and the environment. It is estimated that burning one tonne of rice stubble releases three kilograms of particulate matter, 60 kilograms of CO, 1.460 kilograms of CO_2, 199 kilograms of ash and two kilograms of SO_2 (Gupta and Sahai 2005).

Table 5-1: Nutrient losses due to burning of residues in Rice growing areas in Australia

Nutrient	Nutrient loss in Australia			
	Concentration in stubble (g/kg)	% lost in burn	Loss (kg/ha)	Total loss from 2.00 Mt
C	400	100	2,400	800.00
N	6.5	90	35	11.78
P	2.1	25	3.2	1.12
K	17.5	20	21	6.92
S	0.75	60	2.7	0.93

The data are calculated from estimates of 2.00 Mt of rice stubble burning in Rice based systems and the nutrient composition of stubble and per cent lost in burning by Dobermann and Fairhurst (2002), as reported by Garji et al. 2000). It is assumed that wheat stubble same nutritional composition as rice stubbles.

NSW rice growers may come under pressure to stop burning crop residues in the future. If burning was not permitted, farmers would have to incorporate or bale and remove stubble in order to sow the following cereal crop. With limited time available to plant winter cereals after rice harvesting, especially for a single farmer managing 200-500 ha of rice farm, incorporation or baling of rice stubbles may prove difficult. If stubble burning was to cease and conventional tillage was the only alternative, it is to be expected that the area of winter cereals directly following the rice crop, would be significantly less.

To overcome the problem of direct drilling wheat into rice residues, research engineers from Australia and India involved in the ACIAR Project LWR/2000/089 'Permanent beds for irrigated rice-wheat and alternative cropping systems in north west India and south east Australia' developed the Happy Seeder. The current prototype of the Happy Seeder machine developed in Pakistan, called the Rocket Seeder, was used to successfully direct drill wheat in 11.8 tonnes per hectare of standing stubble on a rice-wheat farm in Griffith, Australia, in 2010. A machine capable of direct drilling crops into 13-15 tonnes of rice stubble, can be developed within the price range of the current seeders (personal communication, Prof John Blackwell, Charles Sturt University, Wagga Wagga).

As is the case in India, stubble retention through the use of Happy Seeder has potential agronomic benefits, in addition to reducing air pollution and retention of nutrients and organic matter. Stubble retention leads to significant improvements in soil health and structure. These include increased nitrogen and phosphorus fixation as a result of providing more suitable environment for soil biota, improved disease resistance in crops owing to improved soil and plant health, and increased water holding capacity due to increased levels of organic matter and soil aeration (Australian Government 2006).

Adoption of the Happy Seeder involves initial capital investment as well as ongoing repairs and maintenance costs. An understanding of the significance of these costs is required to gauge the net benefits to industry from adoption and inform the development of policies related to stubble burning. In the following section we report the findings of a preliminary assessment of Happy Seeder use in an Australian context.

5.3 Assessment of Happy Seeder in an Australian context

5.3.1 Methodology

The assessment was based on a partial budgeting approach which focuses on the net benefits and costs associated with adoption of the Happy Seeder technology. The analysis was carried out from a financial perspective, although some economic, social and environmental benefits/costs were also identified without quantifying the value of these benefits[28].

The study area chosen for this analysis was the Murrumbidgee Valley of NSW with a focus on the MIA and CIA. The majority of irrigated farms are rice-winter cereals-sheep based mixed farms. Due to the low profitability of sheepmeat and wool in the late nineties and severe drought conditions during the last decade, most rice growers moved to more intensive rice-winter cereals based cropping rotations. Around 75-85 per cent of farmers in the MIA and CIA follow crop dominated farming systems. A rice–winter cereal based farming system was used in this analysis to estimate the potential benefits of the Happy Seeder in southern NSW.

Many of the changes to production and costs induced by the adoption of Happy Seeder can be captured in a gross margin. A gross margin (GM) is the gross return from a crop (yield times price) less the variable costs of production, such as tillage, seed, fertiliser, irrigation water, plant protection, fuel, harvesting, crop insurance and marketing. Overhead and operating costs that do not vary with the level of production, such as rent, wages to permanent labour, interest and depreciation etc, are not considered.

With Happy Seeder involving a different stream of benefits and costs over time, all values need to be expressed in terms of their present values through the practice of discounting. The benefits and costs of the adoption of the Happy Seeder were compared with other wheat establishment practices over a 30 year period. The net present value (NPV) of the crop gross margin (GM) was calculated as the sum of the discounted annual GM's from the crops in the rotation, using Equation 4:

$$\mathbf{NPV} = \sum_{t=1}^{n} GM_i / (1 + rate)^t \qquad (4)$$

where *rate* is the real discount rate and $GM_1, GM_2, \ldots, GM_t$ are the gross margins for years 1 to *n*. In this analysis the real discount rate used in the analysis was 7 per cent per annum[29]), while the period *n* was 30 years.

The gross margins used in the assessment relate to a particular sequence of crops (a rotation). While gross margins typically deal with only one crop at a time, farmers often grow a sequence of crops on the same field following a particular rotation in order to manage soil fertility and the incidence of weeds and diseases. For rice growers in southern NSW, the typical rotation is rice, rice/wheat, long fallow wheat, canola, wheat and fallow. To estimate the potential benefits of the Happy Seeder, we considered a six year period of rice and winter cereals based rotations both with and without burning crop residues.

Stubble management practices can influence farm costs associated with the use of irrigation water, fertiliser, weedicides and the extent of machinery operations. An increase in yield also leads to an increase in the cost of some variable inputs and operations, such as harvesting. Therefore, the variable costs and returns of growing wheat and other crops after rice with different tillage and/or stubble management techniques were calculated separately.

[28] In a financial evaluation the values for inputs and outputs reflect the prices actually paid and received by farmers. In an economic analysis, the values of inputs and outputs reflect the placed on them by society. For example, in a financial evaluation CO2-e emissions arising from stubble burning are not relevant as they do not impact on the welfare of the farmer, whereas they are relevant to an economic analysis with its focus on the gains to society overall.
[29] NSW Treasury recommended rate.

Stubble retention (by mulching or incorporation) will save some nitrogen, phosphorus, potassium and sulphur, which would otherwise be lost by burning (Table 5.2). Stubble retention also affects soil fertility in other positive ways and possibly biotic factors, such as weed diversity and the weed seed bank, and the incidence of pests and diseases. The effects vary depending on the method of stubble retention.

With a carbon:nitrogen (C:N) ratio in rice stubble of around 100:1, incorporation results in temporary immobilisation of inorganic nitrogen. To avoid adverse impacts on the crop during the first few years of rice stubble incorporation, more nitrogen fertiliser is required. An alternative option is to delay the sowing date for at least two weeks after incorporation. There are however costs related to delaying sowing beyond the optimum date in the form of reduced yield.

5.3.2 Stubble management options and assumptions

5.3.2.1 Stubble management options

To estimate the potential benefits of the Happy Seeder, the study considered six years of rice and winter cereals based rotations both with and without burning crop residues. The following options were assessed as part of the evaluation:

Option 1: Complete burning of rice and wheat stubble
Crop residues are completely burnt before direct drilling wheat after rice or wheat after wheat. It is assumed that burning of residues would require 0.5 man days per field (20 hectares).

Option 2: Incorporation of rice and wheat stubble
Incorporation of crop residues, requiring two runs of discing, 1 of scarifying, 1 of harrowing and 1 run of a seeder for sowing wheat after rice or wheat after wheat.

Option 3: Happy Seeder
Happy Seeder used to direct drill wheat after rice or wheat after wheat in standing crop residues.

Each of the above options implies a certain sequence of crops. These sequences are outlined in Table 5.2. The prospects of growing crops after rice were assumed to be 80 per cent when crops were sown after burning stubble, 60 per cent when direct drilled in standing stubble and 40 per cent when sown after incorporating stubble.

Table 5-2: Cropping rotations with different approaches of managing stubble

Year of rotation	Year 1		Year 2		Year 3		Year 4		Year 5		Year 6	
Season	Sum	Win	Sum	Win	Sum	Win	Sum	Win	Sum	Win	Sum	Win
Option 1: Burning stubbles	R	F	R	OC (B)	F	W	F	C	F	W	F	F
Option 2: Stubble incorporate	R	F	FI	W	F	F	R	F	FI	W	F	F
Option 3: Happy Seeder	R	OC (HS)	F	W (HS)	F	F	R	OC (HS)	F	W	F	FI

R= Rice; C= Canola; W = Conventional wheat; OC= Opportunity wheat crop (sown immediately after rice); F= Fallow; FI= Fallow and incorporate stubble; (B) = Crop sown after burning of rice stubble; (HS)= Crop sown with Happy Seeder

5.3.2.2 Technology assumptions

The potential benefits and costs arising from the use of the Happy Seeder technology concern a broad range of issues as described below:

i) Machinery/diesel savings: Direct drilling wheat using the Happy Seeder is assumed to reduce tractor time by 2.3 hours per hectare compared with conventional tillage and sowing of wheat after incorporating crop residues. It is assumed to take 20 per cent longer than direct drilling wheat after burning rice or wheat residues. Based on an average fuel consumption of 15 litres per hour for a typical 95 horse power tractor, the use of the Happy Seeder would save 35 litres of fuel per hectare. Reduction in the use of machinery would also lead to some reduction in its repair and maintenance and labour cost but these are not valued here.

ii) Water saving: Mulching of stubble helps retain soil moisture and reduce soil evaporation but there is limited information on the extent of water savings. Based on local experience, it is assumed that incorporation or retention of crop residues would reduce water use by 20 per cent in a short fallow situation (20 per cent of 1.5ML/ha) and 10 per cent in a long fallow situation (10 per cent of 3.5ML/ha) (personal communication, Kieran O'Keefe and John Smith, District Agronomists).

iii) Herbicide use: mulching may suppress establishment and growth of weeds, and studies in other countries have shown significant effects of mulching with rice stubble on weeds in wheat (eg., Sidhu et al. 2007, 2008; Rahman et al. 2005). However, there is no scientifically verified evidence of this in an Australian setting. This study has not considered any benefits from saving of use of herbicides.

iv) Disease with stubble retention: Yellow leaf spot is more common in wheat sown into stubble. It is assumed that there will be extra costs of $10 per hectare of fungicide to control yellow rust in wheat sown with the Happy Seeder.

v) Fertiliser use: In the analysis it is assumed that wheat sown in standing stubbles or after incorporating rice or wheat stubble will need 5 per cent more nitrogen due to immobilisation of nitrogen from microbial activity in breaking down stubbles in the short term. This additional nitrogen is required over the first three years, no additional nitrogen is required in years 4-5, while a saving of 5-10 per cent nitrogen is assumed to occur from year 6 onwards.

vi) Yield: The analysis assumes the same yield of wheat sown by all methods. Long-term experiments of Sidhu and Beri (2005) found no significant increase in yield of wheat from incorporation of rice stubble compared to wheat sown after burning of stubble. However, Sidhu *et al*. (2007) found an average yield increase of about 10 per cent from sowing with the Happy Seeder compared with conventional farmer practice in northern India. A sensitivity analysis was undertaken of a 5 per cent increase in wheat yield from stubble retention or incorporation.

vii) Saving of labour on field preparation and irrigation water: Direct seeding of wheat using the Happy Seeder would help save 2.5 hours per hectare of operator's time relative to incorporation of stubbles and a saving of 3 hours per hectare relative to sowing after burning residues. The study has not placed a value on these savings.

viii) Cost of Happy Seeder use: It is assumed that the capital and operating costs of the Happy Seeder and capacity of tractor required to operate the machine would be at par with the current seeders being used for growing wheat in the rice belt in Australia. The Happy Seeder would take 20 per cent extra time to direct drill wheat in standing stubble compared to the time taken for growing wheat after burning or incorporating stubbles.

5.3.3 Results

5.3.3.1 Comparison of gross margins

The benefits and costs described above were used to develop gross margin budgets for rice and wheat under the three stubble management approaches. The analysis drew on 2010-11 input costs and output prices. The results are presented in Table 5.2.

Table 5-3: Gross Margin ($/ha) of Alternative Stubble Strategies

	Gross margins ($/ha)	Crop yield (t/ha)
Option 1: Complete burning of rice and wheat stubble		
Rice	1,535	10
Wheat (Opportunity Crop)	338	4
Wheat – main season	516	5
Canola standard	594	2.5
Option 2: Incorporation of rice and wheat stubble		
Rice	1,535	10
Wheat (Opportunity Crop)	260	4
Wheat – main season	426	5
Option 3: Happy Seeder		
Rice	1,535	10
Wheat (Opportunity Crop)	334	5
Wheat – main season	502	5

5.3.3.2 Net present value results

Net present value (NPV) results for three alternative stubble management strategies are reported in Table 5.5. Option 1 involving the complete burning of rice and wheat stubble (current practice), had the highest NPV of $11,304 and was the most preferred option. Option 3 involving the use of the Happy Seeder had a NPV of $9,923, some 12 per cent lower than Option 1. Option 2 was the least preferred having a NPV of $8,689, some 23 per cent lower than the burning of stubbles.

Table 5.5: NPV results

Stubble management strategy	NPV of gross margin ($/ha)
Option 1: Complete burning of rice and wheat stubble	$11,304
Option 2: Incorporation of rice and wheat stubble	$8,689
Option 3: Happy Seeder	$9,923

In comparison to Option 2, the use of the Happy Seeder technology in wheat production would help save 35 litres of fuel and 3.5 man hours per hectare from reducing the use of tractors/machinery. In addition, it would reduce on-farm greenhouse gas emission from burning fuel (95 kilograms per year less CO_2 emitted). There may also be some longer term benefits from a reduction in use of nitrogen fertiliser due to mulching and zero tillage which may reduce greenhouse gas emission through carbon sequestration. There may also be some small community health benefits from the reduction in gases and other substances released from burning stubbles.

5.3.4 Summary

The analysis supports current practice of burning rice stubbles as the most profitable option for Australian farmers under existing policy settings. In the absence of any tightening in policy settings around the burning of stubbles, or the development of carbon offset markets or alternative uses of rice, that reward farmers for stubble retention, it seems that stubble burning will remain widespread.

While the assessment indicates that the returns associated with the use of a Happy Seeder technology are insufficient to promote adoption, relatively small changes in key parameters that either influence the effective costs of the technology (improved work rates) or the benefits (yield, carbon sequestration benefits associated with stubble retention) may close the gap. Given some uncertainties in the policy environment, particularly around the development of carbon markets, some further R&D would be consistent with the notion of broadening future options around stubble management in the Australian rice industry.

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APPENDIX 1: METHODOLOGY FOR ESTIMATION OF THE ECONOMIC COST OF AIR POLLUTION FROM RICE STUBBLE BURNING

Economic Valuation Methodology

Air quality affects the utility of individuals and an economic value exists. There are several ways to capture this economic value, viz., dose-response, revealed preferences and contingent valuation methods. The dose-response method assumes a relationship between air quality and morbidity (and/or mortality). It puts a price on air quality without retrieving people's preferences for the good. The mechanical relationship of the dose response function does not take into account consumer behaviour.

The revealed preference method assumes that the consumers are aware of the costs/benefits of air quality and are able to adjust their behaviour to reveal their preferences. Utilising this method requires estimates of willingness to pay (WTP) or willingness to accept (WTA) on the basis of a consumer choice model aimed at measuring the strength of association between health effects and contaminated air quality.

Suppose an individual maximizes his/her utility through expenditure on marketed goods and services, X.[30] The utility depends not only on X but also on the state of health, H of an individual which is affected by the level of air quality (non-marketed good). It is further assumed that the contaminated air quality, P is beyond the control of individuals, but individuals can at least partially reduce the effects of pollution by incurring defensive expenditure, D. The utility function is defined as:

$$U(X, D; P) = H(D, P)U(X) \qquad (1)$$

where $U_X>0$, $U_{XX}<0$, $H_D>0$, $H_P<0$, $H_{DD}<0$, $H_{PP}<0$

The state of health affects an individual's work performance and hence the wage income. Moreover, it is also possible that the contaminated air quality make the individual so sick as to be completely incapacitated. During the time the individual is under this condition, he/she is absent from work and loses wage income completely. Therefore 'sick time', S, can also be assumed to be a function of defensive expenditure and contaminated air quality,

$$S = S(D, P) \qquad (2)$$

where $S_D<0$, $S_P>0$, $S_{DD}>0$, $S_{PP}>0$

The equation (1) is maximized subject to the following constraints:

The time constraint is:

$$W + S = T \qquad (3)$$

where W is the work time and T is the total time available. The income (resource) constraint is:

[30] Harrington *et al*. (1989) take the individual utility as a function of expenditure on marketed goods and services, X, and leisure time, L. Since in developing countries especially in rural areas people are largely living in the conditions of poverty, we assume that individual utility is a function of marketed goods and services only.

$$I + wH(D,P)W \geq mS + D + X \tag{4}$$

where mS is the medical expenses which are assumed proportional to illness, S, I denotes non-wage income and w is the wage rate.

The Lagrangian of the problem is:

$$\Pi = H(D,P)U(X) + \lambda[I + wH(D,P)(T - S) - D - X - mS] \tag{5}$$

The first-order optimization conditions are:

$$\begin{aligned} \Pi_X &= H(D,P)U_X - \lambda = 0 \\ \Pi_D &= H_D U + \lambda H_D wW - \lambda HwS_D - \lambda - \lambda mS_D = 0 \end{aligned} \tag{6}$$

Using the envelope theorem, Harrington *et al*. (1989) obtain the individual willingness to pay (WTP) as:

$$WTP = -\left(\frac{H_D U}{\lambda} + H_D wW\right)\frac{H_P}{H_D} + \left(HwS_D + mS_D\right)\frac{S_P}{S_D} \tag{7}$$

and the marginal loss of social welfare (SW) associated with individual responses to deterioration in air quality, therefore, is:

$$\begin{aligned} \frac{\partial SW}{\partial P} = -\frac{U}{\lambda}\frac{dH}{dP} & \quad \text{(Direct disutility of illness)} \\ - w \times W\frac{dH}{dP} & \quad \text{(Lost work productivity)} \\ - Hw \times W_P & \quad \text{(Value of lost time during illness)} \\ + m\frac{dS}{dP} & \quad \text{(Medical expenses)} \\ + D_P & \quad \text{(Defensive expenditure)} \end{aligned} \tag{8}$$

Equation (8) shows that the cost of illness caused by contaminated air can be grouped into five categories. The term direct disutility is very subjective and it is very difficult to find its monetary value. The second term, lost work productivity, measures the value of loss caused by the illness due to lower work productivity. This loss is caused when the sick person is present for work but is not able to work with his/her full productivity. The third term measures the loss in social welfare due to illness absence of individuals from work. The last two terms measure expenses individual incur for defensive and mitigating activities to combat air contamination.

Figures on the defensive activities of individuals were not able to be obtained through the survey conducted as part of this study, therefore only two of the above values were measured: medical expenses and value of lost time through illness. Thus our measure of social loss due to contaminated air represents a lower bound estimate.

Estimation Strategy

To obtain estimates of social welfare loss due to contaminated air in terms of health damages, the following two equations consisting of demand function for medical expenses (*mS*) and the workdays lost due to illness (S), were estimated:

$$mS = \alpha_0 + \alpha_1 SPM + \alpha_2 SO_2 + \alpha_3 SMOKING + \alpha_4 DRINKING + \alpha_5 PerCapitaAssets + \alpha_6 SEX + \alpha_7 AGE + \alpha_8 EDUCATION + \alpha_9 OCCUPATION + \varepsilon_1 \quad (9)$$

and

$$S = \alpha_0 + \alpha_1 SPM + \alpha_2 SMOKING + \alpha_3 DRINKING + \alpha_4 PerCapitaAssets + \alpha_5 SEX + \alpha_6 AGE + \alpha_7 EDUCATION + \alpha_8 OCCUPATION + \varepsilon_2 \quad (10)$$

where:

mS =	Medical Expenses: mitigating activities or medical expenses include expenses incurred as a result of air pollution related diseases. These expenditures include costs of medicine (formal as well informal), doctor's fee, diagnostic tests, hospitalization, and travel to doctor's clinic during the two months of rice harvesting.
S =	Workdays Lost: the number of workdays lost per person during the two rice harvesting months of October and November due to diseases/symptoms associated with air pollution.
PM and SO_2	Particulate matter (PM_{10}) and Sulfur Dioxide, respectively: These are the averages of the ambient emission levels observed during the monitoring period measured in $\mu g/m^3$.
SMOKING	is: measured as a dummy variable equal to 1 if the individual has a smoking habit, otherwise 0.
DRINKING	is measured as a dummy variable equal to 1 if the individual has an alcohol drinking habit, otherwise 0.
PerCapitaAssets	represents wealth measured in Indian rupees (₹).
SEX	is a gender variable measured as dummy variable equal to 1 for male and 0 for female.
AGE	is the age of the individual measured in number of years.
EDUCATION	is coded as follows: 1 = illiterate; 2 = below primary; 3 = primary; 4 = middle; 5 = secondary/metric; 6 = technical; 7 = graduate; 8 = post-graduate and above
OCCUPATION	is measured as a dummy variable equal to 1 if the individual is in the occupation of self-farming or agricultural labourer, 0 otherwise.

The dependent variable in equation (9) is a censored variable, i.e., the dependent variable is zero for corresponding known values of independent variables for part of the sample. Therefore, we use the Tobit model for estimating the demand for mitigating activities:

$$mS_i = \alpha + \beta x_i + u_i \text{ if } RHS > 0$$
$$= 0 \quad \text{otherwise} \quad (11)$$

where mS_i refers to the probability of the i^{th} individual incurring positive medical expenditure and x_i denotes a vector of individual characteristics, such as assets, age, sex, education, pollution parameter etc.

In equation (10) the dependent variable is a count of the total number of workdays lost due to air pollution related illness by an individual during the particular period; therefore, there are zeros for many observations. In this case a Poisson regression model is appropriate as it considers the predominance of zeros and the small values and the discrete nature of the dependent variable. The least square and other linear regression models do not take into account these features. The Poisson regression model can be stated as follows:

$$prob(Y_i = y_i / x_i) = \mu_i^{y_i} e^{-\mu_i} / y_i,\ y_i = 0, 1, 2, \ldots\ldots\ldots \quad (12)$$

This equation is non-linear in parameters; therefore, for estimation purpose by taking its natural log we convert it into an equation which is linear in parameters. Note that the Poisson regression model is restrictive in many ways. For example, the assumption that the conditional mean and variance of y_i, given x_i are equal, is very strong and fails to account for over dispersion.[31] The data used in the estimation of equations 9 and 10 are provided in Table A1.1.

Table A1.1: Variables Used in the Regression Analysis

Variable	Mean	Standard Deviation	Maximum	Minimum	Percent
Formal Medical Expenses (₹)	39.26	165.05	2700.00	0.00	
Informal Medical Expenses (₹)	19.46	66.62	450.00	0.00	
Workdays Lost	0.06	0.72	15.00	0.00	
Age	31.35	18.50	90.00	1.00	
Education	3.14	1.77	8.00	1.00	
Per Capita Assets (₹)	64469	78377	539467	250	
Male					54.41
Occupation (Farmers and Agricultural labourers)					26.32
Smoking					2.12
Drinking					5.88
Toxicants					3.29

The Model Results

Tables A1.2 and A1.3 provide the results of parameter estimates of the reduced form equations of mitigation expenditure and workdays lost. In the reduced form these equations are expressed as functions of a common set of socio-economic variables and ambient air pollution expressed in terms of particulate matter (PM_{10}) and SO_2 levels.

The parameter estimates of mitigating expenditure equation are given in Table A1.2. We find there is a positive and statistically significant (at 10 per cent level) association between ambient PM_{10} level and the mitigating expenditure. This implies that individual have to spend a higher amount of money to mitigate the adverse health effects when the particulate level is higher in the ambient environment. The relationship between mitigating expenditure and ambient SO_2 level is negative and statistically insignificant, contrary to expectations. This might be happening as the ambient SO_2 level is within the NAAQS limit in the villages of Punjab.

As expected, the coefficient of the variables such as smoking and drinking behaviour of the individual are found to be positive and statistically significant. These personal habits coupled with ambient air pollution make an individual more prone to asthmatic diseases and as a result they are required to spend more on mitigating activities.

Similarly, we find there is positive and significant relationship between the age of individuals and their mitigating expenses, implying that the marginal effect of age on mitigating expenses is positive. We also observe that there is a positive and statistically significant relationship between

[31] A similar estimation procedure is followed by Gupta (2008).

mitigating expenses and per capita assets. This might be happening because wealthier individuals do not hesitate to take mitigating activities if they are susceptible to some diseases, in comparison to people who have lesser assets.

Table A1.2: Tobit Equation of Total Medical Expenditure (Left censored at 0)

Independent Variable	Coefficient
PM_{10} (+)	0.046 (1.72)*
SO_2 (+)	-5.16 (-0.52)
SMOKING (+)	395.14 (2.62)***
DRIKING (+)	177.94 (1.71)*
Per Capita Assets (+)	0.0009 (2.65)***
SEX	-41.76 (-0.57)
AGE (+)	4.13 (1.74)*
EDUCATION (-)	-9.85 (-0.51)
OCCUPATION (+)	92.58 (1.16)
Constant	-678.69 (-2.73)***
Pseudo R^2	0.014
Log likelihood	-1262.37
Wald Chi^2 (9)	35.74***
Uncensored Observations: 141	Left Censored Observations: 484
Total Observations	625

Notes; Figures in parentheses are t-values
*** Significance at 1% level
** Significance at 5% level
* Significance at 10% level

Table A1.3: Poisson Equation of Workdays Lost

Independent Variable	Coefficient
PM_{10} (+)	0.008 (5.59)***
SMOKING (+)	-14.66 (-0.01)
DRIKING (+)	-0.81 (-0.79)
Per Capita Assets (-)	-0.00001 (-1.78)*

Education raises the awareness level of individuals with respect to environmental problems and related health damage and encourages informed preventative activities. While the estimated coefficient of education is negative, as expected, the relationship between mitigation expenditure and education level was not statistically significant.

Similarly, the individuals who have to work in fields where burning of agricultural residue takes place are thought to be more prone to the adverse effects of pollution in comparison to their counterparts in other occupations, such as salaried individuals. A dummy variable was used to distinguish between occupations (equal to one for farmers and agricultural wage earners and zero for the individuals who are in other occupations), and a positive association between occupation and medical expenditure was identified.

Table A1.3 presents parameter estimates of the reduced form equation of workdays lost. As expected, the coefficient of the PM_{10} variable is positive and statistically significant at 1 per cent level implying that the probability of losing workdays increases as the concentration of particulate matters in the ambient environment increases. Education increases awareness level and helps in taking preventative action and as a result a more educated individual could be expected to lose less workdays. Estimation of a negative association between education level and workdays lost confirmed this expectation. Similarly, wealthier individuals can spend money on medical and preventative activities and this was reflected in a negative relationship between per capita assets and workdays lost.

The welfare loss in terms of health damage due to an increase in the concentration of particulate matter from rice stubble burning in the ambient environment was estimated in terms of the increase in medical expenditure on mitigating activities and the opportunity cost of workdays lost, and is presented in Table A1.4.

Table A1.4: Welfare Loss Due to Increased Air Pollution in Rural Punjab

	Representative individual	Rural Patiala District	Total Rural Punjab
	(₹)	(₹ millions)	(₹ millions)
Medical Expenditure	2.17	2.35	36.52
Opportunity Cost of Workdays Lost	2.35	2.54	39.57
Total Welfare Loss	4.52	4.89	76.09

To estimate welfare loss in terms of increased medical expenditure we need to obtain the marginal effects. The marginal effect in the case of Tobit estimation could be computed by taking partial derivatives of mitigating expenditure equation with respect to PM_{10} and multiplying by the probability of the dependent variable taking the non-zero values.

If the ambient PM_{10} level is reduced from the level observed during the harvesting period of rice in rural Punjab to the safe level (i.e., a reduction of 207 $\mu g/m^3$ since the safe level defined under NAAQS is 100$\mu g/m^3$ for the 24 hours average), the estimated reduction in medical expenditure turns out to be ₹2.17 for the months of October and November for a representative person.

Total rural population projected for October 2008 based on Census 2001 is 1.083 million and 16.839 million for the district of Patiala and the state of Punjab, respectively. Extrapolating this welfare loss for the entire rural population of Patiala and Punjab, the increase in medical expenditure at these regional levels arising from rice stubble burning is estimated as ₹2.35 million and ₹36.52 million, respectively.

To estimate the marginal effects of a reduction in the PM_{10} level on workdays lost, we differentiated partially the reduced form equation of workdays lost with respect to PM_{10}. The Poisson estimates show that one $\mu g/m^3$ increase in PM_{10} results in a marginal loss of 0.0000946 days for a representative individual in the two harvesting months. If the PM_{10} level is reduced from the current level to the safe levels during rice harvesting period, the estimated gain in workdays is 0.03 per individual. In monetary terms, the loss in terms of workdays lost for a representative individual is estimated to be ₹2.35, ₹2.54 million for the rural Patiala district and ₹39.57 million for rural Punjab State (assuming a wage rate of ₹120 per day).[32]

Hence, the total monetary loss (due to lost workdays and increased medical expenditures) caused in terms of health damages due to an increase in ambient PM_{10} level beyond the safe level for the rural areas of Patiala district and Punjab state is estimated at ₹4.89 million and ₹76.09 million, respectively.

These estimated losses should be considered the lower bound of health damage caused by rice stubble burning in rural Punjab. The losses would be much higher if expenses on averting activities, productivity loss due to illness, monetary value of discomfort and utility could have been counted,

[32] A wage rate fixed for the state of Punjab under National Rural Employment Guarantee Act (NREGA).

and the economic cost of motor vehicle accidents caused by low visibility. There are of course, additional non-health related monetary costs of burning to the farmers in terms of additional fertilizer, pesticides and irrigation, and losses of soil nutrients, vegetation and bio-diversity.

APPENDIX 2: REGULATORY CONSTRAINTS ON CROP RESIDUE BURNING IN NSW

Protection of the Environment Operations Act 1997

Division 2 Air pollution from fires
133 Prohibition by EPA of burning in open air or incinerators

(1) This section applies if the EPA is of the opinion that weather conditions are such that the burning of fires in the open or in incinerators while those conditions persist will contribute or is likely to contribute to air pollution to such an extent that the making of an order under this section is warranted.
(2) The EPA may, by order published in accordance with this section, prohibit, unconditionally or conditionally, the burning of fires in the open or in all or any specified classes of incinerators.
(3) An order under this section has effect for such period (not exceeding 7 days) as is specified in the order, but may be revoked by a further order under this section.
(4) An order under this section must be:
(a) published in a daily newspaper circulating throughout the State not later than on the day on which the order is to take effect, or
(b) broadcast by radio or television throughout the area of the State to which it relates not later than on the eve of the day on which the order is to take effect.
(5) An order under this section may be limited in any way specified in the order, including:
(a) to specified areas or classes of areas,
(b) to specified persons or classes of persons,
(c) to specified times or circumstances,
(d) to specified purposes or classes of purposes.
(6) An order under this section has effect even though it prohibits burning that is permitted by any regulation relating to the burning of fires.

134 Directions by authorised officers concerning fires

(1) This section applies if an authorised officer is of the opinion that a fire is burning in or on any premises and:
(a) the fire is prohibited by an order of the EPA under this Division or by the regulations, or
(b) air pollution from the fire is injurious to the health of any person or is causing or is likely to cause serious discomfort or inconvenience to any person.
(2) The authorised officer may, by notice in writing given to:
(a) the occupier of the premises or person apparently in charge of the premises, or
(b) the person apparently in charge of the fire,
direct the occupier or other person to whom the notice is given to extinguish the fire immediately.
(3) The authorised officer may, by that notice, also direct the occupier or other person not to light or maintain a similar fire in or on the premises during such period (not exceeding 48 hours) as is specified in the notice.
(4) A notice under this section may be revoked by a further notice under this section.

135 Offence

A person who, without reasonable excuse, does not comply with an order or notice under this Division is guilty of an offence.

Protection of the Environment Operations (Clean Air) Regulation 2010

Division 2 Control of burning generally
10 General obligation to prevent or minimise air pollution

(1) A person who burns anything in the open or in an incinerator must do so by such practicable means as are necessary to prevent or minimise air pollution.
Maximum penalty: 100 penalty units (in the case of a corporation) or 50 penalty units (in the case of an individual).
(2) Without limiting subclause (1), the means of preventing or minimising air pollution may include the following:
(a) taking into account the potential for smoke impacting on any person having regard to:
(i) wind direction, and
(ii) weather conditions, and
(iii) the length of time that the material being burnt is likely to burn,
(b) taking reasonable measures to ensure that the material being burnt is not wet,
(c) burning only material that is suitable for disposal by burning, having regard to possible effects on human health and the environment.

11 Prohibition on burning certain articles

(1) A person must not burn a prohibited article:
(a) in the open, or
(b)in an incinerator that is not authorised or controlled by a licence under the Act.
Maximum penalty: 100 penalty units (in the case of a corporation) or 50 penalty units (in the case of an individual).
(2) It is not an offence under this clause to burn a tyre for the purposes of the giving of instruction in methods of fire fighting by an officer or member of a fire fighting authority (within the meaning of the *Rural Fires Act 1997*), or by a fire control officer (within the meaning of the *Rural Fires Act 1997*), when acting in his or her official capacity.
(3) The EPA may, by written notice given to a public authority, exempt the public authority from the operation of subclause (1).
(4) The EPA may grant such an exemption only in relation to the burning of prohibited articles in the course of any of the following activities:
(a) research to improve safety in relation to the flammability of materials and smoke reduction (including the development of testing procedures),
(b) training of fire-fighters,
(c) rating of the effectiveness of fire extinguishers and fire suppression systems,
(d) testing undertaken to certify that manufactured or imported products comply with Australian Standards or International Standards or meet any legislative requirements placed on them.
(5) An exemption:
(a) is subject to any conditions that may be specified in the written notice by which it is granted, and
(b) may be amended or revoked by means of a further written notice given to the public authority, and
(c) unless sooner revoked by the EPA, remains in force:
(i) for a period of 12 months from the date it is granted, or
(ii) for such other period as is specified in the written notice by which it is granted, and
(d) extends to apply to any person acting at the direction of the public authority to which it is granted.
(6) In this clause, ***prohibited article*** means any of the following:
(a) tyres,
(b) coated wire,
(c) paint containers and residues,
(d) solvent containers and residues,
(e) timber treated with copper chromium arsenate (CCA) or pentachlorophenol (PCP).

Division 3 Control of burning in local government areas

12 Offences

(1) A person must not burn anything:
- (a) in the open, or
- (b) in an incinerator,

in a local government area specified in Part 1 of Schedule 8 except in accordance with an approval.

Maximum penalty: 100 penalty units (in the case of a corporation) or 50 penalty units (in the case of an individual).

(2) A person must not burn any vegetation:
- (a) in the open, or
- (b) in an incinerator,

in a local government area specified in Part 2 of Schedule 8 except in accordance with an approval.

Maximum penalty: 100 penalty units (in the case of a corporation) or 50 penalty units (in the case of an individual).

(3) A person must not burn anything (other than vegetation):
- (a) in the open, or
- (b) in an incinerator,

in a local government area specified in Part 3 of Schedule 8 except in accordance with an approval.

Maximum penalty: 100 penalty units (in the case of a corporation) or 50 penalty units (in the case of an individual).

(4) It is not an offence under this clause:
- (a) to cook or barbecue in the open, or to light, maintain or use a fire for recreational purposes such as camping, picnicking, scouting or other similar outdoor activities, so long as only dry seasoned wood, liquid petroleum gas (LPG), natural gas or proprietary barbecue fuel (including a small quantity of fire starter) is used, or
- (b) to burn vegetation, in the course of carrying on agricultural operations, on premises on which the vegetation grew, including:
  - (i) the burning of vegetation for the purposes of clearing (other than for construction), or
  - (ii) the burning of stubble, orchard prunings, diseased crops, weeds or pest animal habitats on farms, or
  - (iii) the burning of pasture for regenerative purposes, or
- (c) to burn anything for the purposes of the giving of instruction in methods of fire fighting by any of the following persons when acting in his or her official capacity:
  - (i) an officer or member of a fire fighting authority (within the meaning of the *Rural Fires Act 1997*),
  - (ii) a fire control officer (within the meaning of the *Rural Fires Act 1997*),
  - (iii) an industrial fire control officer, or
- (d) to burn anything under the authority of, and in accordance with, a bush fire hazard reduction certificate issued under the *Rural Fires Act 1997*, or
- (e) to burn anything in an incinerator that is authorised or controlled by a licence under the Act, or
- (f) to burn anything in an incinerator that:
  - (i) is equipped with a primary and secondary furnace, and
  - (ii) is designed, maintained and operated in a manner that ensures the maintenance of appropriate temperatures for the complete combustion of anything that the incinerator is designed to burn and prevents the escape of sparks or other burning material, and

(iii) is equipped with suitable equipment that is designed, maintained and operated for the purposes of controlling air impurities in the exhaust gas once the incineration process has been completed, and
(iv) is not installed in a residential building comprising home units, flats or apartments, or

(g) to burn air impurities by the process known as flaring if the flare is designed, maintained and operated so as to prevent or minimise air pollution.

Note. See clause 49 (a) for an operating requirement for flares.

(5) It is not an offence under subclause (3) to burn domestic waste on residential premises in a local government area specified in Part 3 of Schedule 8, being premises on which the waste was generated, if domestic waste management services are not available to those premises.

13 Approval for certain fires or incinerators

Note. An approval may be granted so as to permit burning in circumstances where it would otherwise be prohibited under this Division.

However, burning may still be prohibited by an order of the EPA under section 133 of the Act or by an order under the *Rural Fires Act 1997*.

(1) The EPA may grant an approval for the purposes of this Part:
(a) to any class of persons—by means of a notice published in the Gazette, or
(b) to any particular person—by means of a written notice given to the person.

(2) The council of a local government area specified in Part 2 of Schedule 8 may grant an approval for the purposes of this Part in respect of the burning of dead and dry vegetation on the premises on which the vegetation grew in the local government area:
(a) to any class of persons—by means of a notice published in a local newspaper circulating in the local government area, or
(b) to any particular person—by means of a written notice given to the person.

(3) Before granting an approval for the purposes of this Part, the EPA or local council concerned must take the following matters into consideration:
(a) the impact on regional air quality and amenity,
(b) the impact on local air quality and amenity,
(c) the feasibility of re-use, recycling or other alternative means of disposal,
(d) any opinions of the sector of the public likely to be affected by the proposed approval,
(e) in the case of an approval under subclause (2) (a)—any opinions of the EPA in relation to the proposed approval.

(4) An approval:
(a) is subject to such conditions (if any) as are specified in the notice by which the approval is granted, and
(b) may be amended or revoked by means of a notice given or published in the same way as the original notice granting the approval was given or published, and
(c) remains in force for a period of 12 months (or such other period as is specified in, or implied by, the approval) from the date it is granted unless sooner revoked by the authority that granted it.

Rural Fires Act 1997

Division 1 Duty to prevent bush fires

63 Duties of public authorities and owners and occupiers of land to prevent bush fires

(1) It is the duty of a public authority to take the notified steps (if any) and any other practicable steps to prevent the occurrence of bush fires on, and to minimise the danger of the spread of a bush fire on or from:
(a) any land vested in or under its control or management, or
(b) any highway, road, street, land or thoroughfare, the maintenance of which is charged on the authority.

(2) It is the duty of the owner or occupier of land to take the notified steps (if any) and any other practicable steps to prevent the occurrence of bush fires on, and to minimise the danger of the spread of bush fires on or from, that land.
(3) A public authority or owner or occupier is liable for the costs incurred by it in performing the duty imposed by this section.
(4) The Bush Fire Co-ordinating Committee may advise a person on whom a duty is imposed by this section of any steps (whether or not included in a bush fire risk management plan) that are necessary for the proper performance of the duty.
(5) In this section:
notified steps means:
(a) any steps that the Bush Fire Co-ordinating Committee advises a person to take under subsection (4), or
(b) any steps that are included in a bush fire risk management plan applying to the land.

64 Occupiers to extinguish fires or notify fire fighting authorities

(1) If a fire (not being a fire or part of a fire lit under the authority of this Act or any other Act) is burning on any land at any time during a bush fire danger period applicable to the land the occupier of the land must:
(a) immediately on becoming aware of the fire and whether the occupier has lit or caused the fire to be lit or not, take all possible steps to extinguish the fire, and
(b) if the occupier is unable without assistance to extinguish the fire and any practicable means of communication are available, inform or cause to be informed an appropriate officer of the existence and locality of the fire if it is practicable to do so without leaving the fire unattended.
(2) In this section, ***appropriate officer*** means:
(a) if the fire is burning within any fire district constituted under the *Fire Brigades Act 1989*—the nearest available officer or fire fighter of the fire brigades in the fire district, or
(b) if the fire is burning outside any such fire district—the nearest available:
(i) officer or member of a rural fire brigade, or
(ii) fire control officer or deputy fire control officer, or
(iii) member of staff of the Department of Industry and Investment, or
(iv) member of staff of the Department of Environment, Climate Change and Water.
Maximum penalty: 20 penalty units or imprisonment for 6 months, or both.

Division 5 Permits and notice requirements

85 Definitions

In this Division:
appropriate authority, in relation to a fire permit in respect of land, means:
(a) in the case of land in a rural fire district—the Commissioner of the NSW Rural Fire Service,
(b) (Repealed)
(c) in the case of land in a fire district—the Commissioner of NSW Fire Brigades.
(d) (Repealed)
land clearance means clearing land of bush, stubble, scrub, timber, trees, grass or vegetative or other material.
light a fire includes:
(a) maintain or use a fire, and
(b) cause a fire to be lit, maintained or used.

86 Notice and certain authorities required before certain fires lit

(1) A person who lights a fire on land:
(a) for the purpose of land clearance or for burning any fire break, or

(b) in circumstances in which doing so would be likely to be dangerous to any building,

is guilty of an offence unless the person has given notice in accordance with the regulations to the persons prescribed by the regulations.

Maximum penalty: 50 penalty units or imprisonment for 12 months, or both.

(1A) A person who lights a fire on land for the purpose of land clearance or for burning any fire break is guilty of an offence unless:

(a) a bush fire hazard reduction certificate has been issued in respect of the land clearance or fire break, or

(b) any approval, consent or other authority required for the land clearance or fire break under the *Environmental Planning and Assessment Act 1979* or any other law has been given.

Maximum penalty: 50 penalty units or imprisonment for 12 months, or both.

(2) Nothing in this section requires an authorised officer of a fire fighting authority to give notice of the lighting of a fire for the purpose of back burning.

Note. An authorised officer is not required to obtain various other approvals or authorities if carrying out an emergency fire fighting act—see Part 6A.

87 Lighting fires for land clearance or fire breaks in bush fire danger period

(1) A person who lights a fire on land for the purpose of land clearance or for burning any fire break during a bush fire danger period that applies to the land is guilty of an offence unless the person:

(a) is authorised to do so by a fire permit issued by the appropriate authority and the person complies with any conditions set out in the fire permit, and

(b) has given notice in accordance with section 86.

Maximum penalty: 50 penalty units or imprisonment for 12 months, or both.

(2) Nothing in this section requires an authorised officer of a fire fighting authority who lights a fire for the purpose of back burning to be authorised to do so by a fire permit or to give any notice before lighting such a fire.

Note. An authorised officer is not required to obtain various other approvals or authorities if carrying out an emergency fire fighting act—see Part 6A.