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Abstract

Burning of rice stubbles is widely practised in Punjab, India, due to a lack of suitable machinery to direct drill wheat into combine-harvested rice residues. Although burning is a rapid and cheap option, and allows quick turn around between crops, it has serious effects on human and animal health due to air pollution, reduced soil fertility due to loss of nutrients and organic matter, and green house gas (GHG) emissions. The recently developed Happy Seeder (HS) overcomes the technical problems associated with direct drilling into rice residues. The primary aim of the present study was to conduct a preliminary evaluation of the direct financial benefits and costs to farmers of use of the HS in comparison with the current practices of straw burning followed by direct drilling or conventional tillage prior to sowing. The results of the evaluation suggest that the HS technology is more profitable than conventional cultivation or direct drilling after burning, and that it is viable for farmers from a financial perspective. The net present value (NPV) of the benefits is highly sensitive to yield; a 5% increase in yield with the HS doubles the increase in NPV of the HS over conventional tillage. The NPV is also quite sensitive to changes in herbicide use, and less sensitive to changes in irrigation water saving and discount rate. Furthermore, there are significant economic, community and environmental benefits through adoption of the technology. For widespread adoption of the technology, a range of potential mechanical, technical, social, institutional and policy constraints need to be considered and addressed in conjunction with a detailed economic assessment of the HS technology.

1. Introduction

Rice-wheat cropping is the predominant and most profitable farming system in north-west India, especially in Punjab State, where it accounts for more than 2.6 Mha or 60% of the total net sown area (Government of Punjab 2005). Timeliness of field operations for both rice and wheat is a key element in fitting both crops in each year and achieving high yields. The majority of the rice and wheat in Punjab is combine harvested, leaving anchored straw 0.3-0.6 m high, and loose straw in windrows (Gajri et al. 2002). Management of the rice stubbles (more than 6 t/ha), is a major problem in the system. Burning is widely practised due to the lack of suitable machinery to direct drill wheat into the combine harvested rice residues. This is a rapid, cheap option which allows quick turn around between crops, hence more than 90% of the 17 Mt of rice stubble in Punjab is burnt each year (Fig 1 & 2). Field hygiene benefits of burning on reducing weeds, insects, mice and pathogens are of unknown importance.

Fig 1 & 2: Burning of rice residues causing air pollution in Punjab

However, burning rice stubbles results in serious air pollution with adverse effects on human and animal health (Gupta and Sahai 2005, Lal 2006, Aggarwal 2006 and Canadian Lung Association 2007), and increased GHG emissions (Prasad 2006, Garg 2006). Burning also results in large loss of nutrients and organic matter (Table 1). After burning, the seedbed for wheat is typically prepared by 1 discing, 2 tyne harrowings and 2 planking (Appendix 1). Wheat is then sown using a tractor operated seed-fertiliser drill. However, zero tillage after stubble burning is now being adopted by many farmers. In 2005-06, around10% of the total area sown to wheat was sown using zero till machines. Less than 1% of farmers incorporate the rice straw, perhaps because more tillage operations are required than after burning (Department of Agriculture, Punjab 2005).

Table 1: Nutrient losses due to burning of rice residues in Punjab in 2001-02

Nutrient	Nutrient loss Punjab			
	Concentration in straw (g/kg)	% lost in burn	Loss (kg/ha)	Total loss from 10.7 Mt(kg)
C	400	100	2,400	4,280
N	6.5	90	35	63
P	2.1	25	3.2	6
K	17.5	20	21	37
S	0.75	60	2.7	5

The data are calculated from estimates of 10.7 Mt of rice straw burning in 2001-02 (Gajri. et al. 2002), straw yield of 6 t/ha (Sidhu et al. 2007), and nutrient composition of straw and per cent lost in burning by Dobermann and Fairhurst (2002)

To overcome the problem of direct drilling 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' (HS). The HS is a tractor-powered machine that cuts and lifts the rice straw, sows into the bare soil, and deposits the straw over the sown area as a mulch (Sidhu et al. 2007, 2008). It combines the stubble mulching and seed and fertiliser drilling operations into one machine in a single pass.

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 straw 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.

Adoption of the HS will involve significant initial capital investment, replacement and maintenance costs. Therefore, before recommending the HS to farmers, it is important to estimate the potential benefits of the HS. This information would also help to identify the total benefits to the industry, inform the development of policies for successful adoption, and estimate the returns to R&D investment.

The main aims of the study presented here were to:

- estimate potential financial benefits to farmers of use of the HS compared to the other current practices of soil and stubble management for sowing wheat after rice
- estimate the costs of adoption of the HS
- identify community and environmental benefits of adoption of the HS
- identify constraints to adoption of the HS
- compare the benefits and costs of adoption of the HS

The methodology for the economic analysis is outlined in Section 2, below, followed by estimation of the potential benefits and costs of adoption of the technology in section 3. In section 4 various community and environmental benefits from adoption of the HS are identified. The results of the analysis and their implications are discussed in section 5. Section 6 discusses the main constraints to adoption of the technology and in the final section some conclusions are drawn.

1.1 Background to the technical development of the Happy Seeder

The original HS was developed by the research engineers of CSIRO Griffith and Punjab Agricultural University (PAU), in July 2001 (Humphreys et al. 2006; Sidhu et al. 2008). The machine consisted of a standard Indian zero till seed drill with inverted T-boots attached by three point linkage behind a forage harvester with a modified chute (Figure 3). This machine was extensively tested for direct drilling wheat in heavy loads of rice residues. Although the results with about 6 t/ha of rice stubble were very encouraging, in some situations establishment was poor due to poor seed/soil contact and uneven distribution of straw.

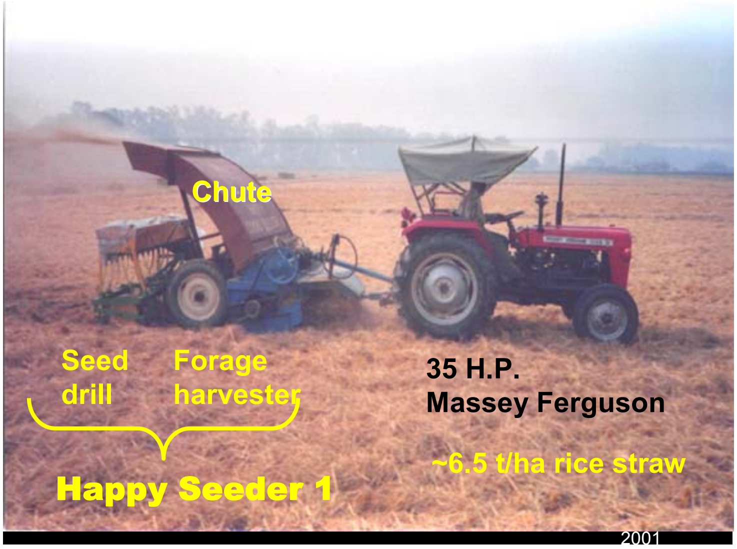

Figure 3. The Original Happy Seeder (photo J. Blackwell)

A second generation of the HS called the Combo$^+$ model was developed in 2004 by combining the forage harvester and seed drill into a single, compact, light weight (540 kg), 2 metre wide machine which can be easily mounted on a three point linkage (Figure 4). *A narrow strip tillage assembly was added in front of the sowing tynes* to improve seed/soil contact on the sandy loam and loam soils in Punjab.

Figure 4: The Combo+ Happy Seeder (photo Dasmesh Mechanic Works Pty Ltd)

Extensive trials undertaken using this machine revealed that wheat can be successfully direct drilled into heavy loads of up to 9t/ha of rice stubble in Punjab (Sidhu et al. 2007, 2008). In addition, the technology has potential application in a range of other cropping systems such as the establishment of mungbeans in wheat residues, soybeans in barley and barley in maize (Humphreys et al. 2006).

However there were still some problems with the technology including restricted straw flow through the chute and clumpy distribution when the straw was moist, impeded establishment from the straw being deposited over the sowing lines with heavy straw loads, and gaps and overlapping of the area sown due to difficulties for the operator in visually identifying the sowing lines.

The third generation – Turbo Happy Seede, that was recently developed by Dasmesh Mechanical Works in collaboration with PAU eliminates the chute, greatly reduces the amount of dust generated, and leaves the sowing lines more exposed and visible, thus overcoming most of the difficulties with the earlier HS models (Figure 5).

Initial trials of the Turbo HS in 2005/06 sowing wheat into rice stubble showed excellent establishment. However, the Turbo HS has not yet undergone full evaluation and is currently being tested in terms of stubble handling performance, power requirements, and crop performance in a range of conditions (stubble load, moisture, soil).

Figure 5. Turbo Happy Seeder (photo Dasmesh Mechanical Works)

2. Methodology

The economic analysis involved a partial budgeting approach in which the additional and foregone annual costs and benefits associated with the HS were compared to estimate the net gains from adoption of the new technology. The analysis was carried out primarily from a financial perspective; some economic, social and environmental benefits were also identified without quantifying the value of these benefits

In undertaking a financial evaluation, it is appropriate to use financial values for all relevant inputs and outputs. 'Financial values' refer to the prices/benefits actually received by farmers for outputs, and actual costs paid by them for inputs used or losses suffered. In an economic analysis (as opposed to the financial analysis presented here) inputs and outputs would be priced at the value placed on them by society. An economic analysis is beyond the scope of this study.
The criterion used in assessing the financial merit of adoption of the HS was the Net Present Value (NPV) of the investment. NPV is the difference between the present

value of benefits of the technology and the present value of costs of the technology. The proposal is deemed to have a positive impact if its NPV exceeds zero.

2.1 Estimation of farm level benefits

The study used a range of techniques to measure the on farm benefits from the adoption of the HS technology on a typical rice-wheat farm in Punjab. The benefits to farmers from adoption of the technology were estimated based on the Combo HS (Sidhu et al. 2008).

Gross margin analysis

The 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 in a GM analysis. Crops and rotations can be compared using GMs as long as there is no significant change in overhead costs between the alternative options being compared.

The cost of some inputs or operations such as irrigation water, fertiliser, weedicide, machinery operations etc. are different under different stubble management regimes. An increase in yield or price also leads to an increase in the cost of some variable inputs and operations such as harvesting, threshing and marketing costs etc. 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.

Crop sequence gross margin analysis

Gross margin (GM) analysis deals with only one crop at a time, whereas farmers grow a sequence of crops on the same field following a particular rotation. Furthermore, selection of an enterprise by a farmer is not always done only on the basis of its profitability as an independent enterprise, but also by its contribution to other enterprises and the total cropping system. To improve soil fertility, farmers can grow nitrogen (N) fixing crops like pulses or crops grown solely for green manuring. While gross margins of such crops may be low or negative, they may reduce input costs, improve soil health and/or increase yield of other crops in the rotation. These crops may also act as a break crop to help to reduce input costs or yield losses from weeds and diseases. However, for rice-wheat farmers in Punjab, the typical rotation is puddled transplanted rice planted in June and harvested in October, followed by wheat sown in November and harvested in April, with no legumes or green manure crops in most of the rice wheat belt during the long fallow (~10 weeks) between wheat harvest and rice transplanting.

Straw retention (by mulching or incorporation) will save considerable amounts of N and some phosphorus, potassium and sulphur, which would otherwise be lost by burning (Table 1). Straw retention also affects soil fertility in other ways, and possibly biotic factors such as weed diversity and the weed seed bank, and the incidence of other pests and diseases. The effects vary depending on the method of stubble retention. With a carbon:nitrogen (C:N) ratio in rice straw of around 100:1, incorporation results in temporary immobilisation of inorganic N. To avoid adverse impacts on the crop during the first few years of rice straw incorporation, more N fertiliser is required, or sowing needs to be delayed for at least 2 weeks after incorporation is completed. However, delaying sowing beyond the optimum date (25 October in Punjab India, Ortiz-Monasterio et al. 1994), reduces yield.

Estimation of the long-term benefits and costs of such changes in straw management and crop sequence requires analysis of the total crop sequence. Therefore, we compared the benefits and costs of the adoption of the HS with those of other current practices of wheat establishment after rice harvest over a 20 year period.

The NPV of the crop GM was then calculated as the sum of the discounted annual gross margins from the crops in the rotation, using Equation 1:

$$\mathrm{NPV} = \sum_{t=1}^{n} GM_i /(1 + rate)^t \qquad \text{Equation 1}$$

where *rate* is the discount rate (7% , real discount rate), and $GM_1, GM_2, \ldots, GM_t$ are the gross margins for years 1 to *n* (n=20 in this study).

2.2 Data and assumptions used in the analysis

The key data and assumptions used in the GM analysis of the potential financial benefits from the adoption of the HS are given below.

Output and input prices

Output prices used in the GM analysis were the government procurement prices for wheat and paddy during 2005-06. Various government agencies purchased more than 90% of the wheat and paddy. The input costs were also estimated using 2005-06 market prices.

Machinery costs

The HS has only been developed and tested over the past 3-4 years, on a limited acreage each year. Furthermore, there is no information in general on the costs involved in farmers using their own machinery for managing stubbles and sowing wheat and other crops after rice, on a typical rice farm in Punjab. Therefore, the cost of use of the HS was based on the contract rate for a Roto-broadcaster which has similar power requirements, capacity and working width as the HS. For consistency, contract rates during 2005-06 for all tillage and sowing operations were also used in the gross margin and the crop sequence analysis.

Cost of hiring casual labour

To meet the peak period demand for labour for different farm operations, farmers in Punjab can easily hire casual labour from the open market at Rs10/h or Rs80/d.

Cost of pumping groundwater (GW)

Due to excessive use of GW for growing rice wheat, the watertable is declining at the rate of 70-80 cm per year. The centrifugal pumps are being replaced by submersible pumps, which are very expensive but more efficient in pumping out deep WG. Submersible pumps now comprise almost 30% of the pumps used for pumping GW.

The operating costs of pumping groundwater were estimated to be Rs.7.34 and Rs 18.00 per irrigation (7.5cm) for using centrifugal and submersible pump respectively. The study has considered the operating costs for pumping GW based on a typical centrifugal pump used in the rice-wheat belt of Punjab (Table 2).

Table 2: Cost of pumping groundwater using centrifugal and submersible pumps in Punjab

	Centrifugal	**Submersible**
Size of motor hp	7.5	7.5
Cost of motor (Rs)	11,000	25,000
Life of motor (years)	20	20
Annual repair and maintenance	10%	10%
Cost of pipes, fittings and structure (Rs/farm)	14000	50000
Total annual cost (R-W) (Rs/acre)	235	575
Total annual cost (wheat) (Rs/acre)	39.00	39.00
Water used (cm/irrigation)	7.5	**7.5**
Cost (Rs/irrigation)	**7.34**	**18.00**

Note: The estimated costs are based on the information provided by the Research Engineers working in the Department of Farm Power and Machinery, PAU Ludhiana, India.

Electricity used in agriculture

In Punjab, almost every farmer uses an electric motor for pumping GW, and pumps more than 240 cm per annum for their rice-wheat system. Electricity is free for farmers, therefore information on the electricity used for irrigation of different crops is lacking. The study has estimated the electricity used for irrigation of different crops for a 7.5 hp (5.6 kW) electric motor (the most common size), on a typical 10 acre (4 ha) rice–wheat farm. It was estimated that 84 kW of electricity is used for an irrigation of 7.5 cm applied to 1 ha.

Emission of carbon dioxide (CO_2)

In Punjab, around 60% of the total electric power is generated in thermal power stations which run on coal and are one of the major sources of GHG emissions in the state. It is estimated that 0.96kg CO_2 are emitted per kWh of electricity generated from coal based power stations (USDOE and US EPA 2000). Similarly it is estimated that 1 litre (L) of petrol when burnt produces 2.3kg of CO_2, whereas, 1 L of diesel emits 2.7kg of CO_2 (US EPA, 2005). These data were used as surrogate values to estimate reduction in GHG emissions from adoption of the HS due to reduction in irrigation as a result of mulching.

3. Potential benefits of the HS

Although potential beneficiaries from the adoption of the HS are farmers, the community and the environment, our main focus in this paper was to identify and estimate the potential financial benefits to the rice/wheat farmers from adoption of the HS. We have also qualitatively identified some of the major off-farm social and environmental benefits of the HS, but we have not attempted to put a monetary value on most of them.

3.1 Benefits and costs of methods of wheat establishment after rice

Establishment of wheat by sowing into rice residues with the HS was compared with the current practices of conventional and zero tillage after stubble burning. The value of the potential benefits and costs of the HS were estimated using the results of the research to date (Sidhu et al. 2007, 2008; Yadvinder-Singh et al. 2008), together with estimates by PAU research and extension staff to fill data gaps.

The potential benefits to farmers of the HS are:

- reduced cost of machinery operations for crop establishment in comparison with conventional tillage (but not in comparison with zero till after straw burning) through reduced diesel consumption, reduced machinery repairs and maintenance, and reduced labour for machinery operations.
- increased yield through improved soil physical, chemical and biological properties
- reduced fertiliser inputs through improved soil fertility
- reduced weed control costs through suppression of weeds by mulching
- irrigation water savings through suppression of soil evaporation
- labour savings – through fewer tillage operations, reduced irrigation time
- electricity savings – through reduced pumping time

3.2 Estimating the value of the benefits of the HS

Yield increase

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, in farmers' fields, Sidhu et al. (2007) found an average yield increase of about 10% from sowing with the HS compared with farmer practice.

Both the HS and the zero till drill allow sowing wheat shortly after rice harvest, although turn around can be faster with the HS because of the time taken for the straw to dry for burning prior to use of the zero till drill. This could be particularly important for basmati rice which is harvested much later than other types, in terms of achieving wheat sowing close to the optimum time for maximum yield. Therefore a sensitivity analysis for increases in wheat yield of 5 and 10% was included.

Fertiliser saved

Retention of rice stubble adds nutrients to the soil (Table 1). However, there is little information on the effect of mulching on fertiliser requirements over time. In the high- yielding rice systems in California (>10 t/ha rice straw, one crop per year), N fertiliser rates were reduced by 20% (27 kg N/ha, equivalent to 59 kg/ha of urea), after 5 years of rice straw retention (Bird et al. 2002). In our analysis we assumed that mulching of rice stubbles would reduce N fertiliser requirement of wheat by 10% (26.5 kg/ha of urea) in the 5th year and by 15% (40 kg/ha urea) from year 10 onwards. We considered that the low soil organic C, sub-tropical climate promoting rapid mineralisation, and high permeability of Punjab soils, would reduce the nutrient benefit of straw retention in comparison with the Californian situation. These fertiliser savings result in a financial benefit of Rs133/ha/yr from year 5 to 10 and Rs199/ha/yr from year 11 to 20 (Table 3).

The analysis assumed no carry over effect of retaining rice straw on N fertiliser requirement for rice. Although the Government of India (GOI) give a large subsidy on fertilisers to encourage their use for food security (GOI, 2006), we have not estimated the economic benefits from saving of N.

Table 3: Value of N fertiliser and herbicide saved in wheat with rice stubble retention

	Value of Savings (Rs/ha)
Fertiliser saved	
- 10% saving each year after 5 years	133
- 15% saving after 10 years	199
Weedicide	
- 50% saving every year	908
Labour saved though irrigation operations	238

Herbicides saved

Mulching suppresses establishment and growth of weeds, and many studies have shown very large effects of mulching with rice straw on weeds in wheat (e.g. Sidhu et al. 2007, 2008; Rahman et al. 2005). Due to the lower population of weeds, farmers may use herbicide less frequently. Therefore, we assumed that mulching would reduce the cost of herbicide by 50%, thus saving Rs908/ha/yr (Table 3).

Diesel saved

Direct drilling wheat using the HS would reduce tractor time by 7.5 hours per ha compared with conventional tillage and sowing, but would take a little longer than use of the zero till drill. Based on an average fuel consumption of 6L/h for a typical 35 HP tractor, use of the HS would save 45 litres of fuel per ha. However, we have costed the use of machinery based on contract rates, which already take into account the diesel savings (and the machinery repair and maintenance and labour savings) through the reduced time taken for field operations.

Water saved

Sowing wheat immediately after rice harvest could reduce the need for pre-irrigation. Both the HS and the zero till drill allow sowing shortly after rice harvest, although turn around can be faster with the HS. Mulching of stubble also helps reduce soil evaporation. In addition to saving the pre-irrigation, it is assumed a farmer also saves 15% from the 1st and 10% from the 2nd irrigation with an overall saving of 30% of water applied to the wheat crop in comparison with conventional tillage (Table 4). However, farmer and researcher experience with zero tillage of wheat in the region indicates similar irrigation water savings of 20-35% or 80-140 mm compared with conventional tillage, with the largest savings in the first irrigation (Humphreys et al. 2007). Therefore the sensitivity analyses included scenarios with no irrigation water saving through adoption of the HS.

Table 4: Total water use and value of water saved from sowing wheat using the HS in the rice wheat farming system in Punjab

Irrigation	Conventional sown wheat (cm/irrigation)	Wheat sown using Zero tillage (cm/irrigation)	Wheat sown using HS (cm/irrigation)	Water savings from wheat sown using the HS (%)
Pre sowing irrigation	10	0	0	100%
First irrigation	7.5	6.38	6.38	15%
Second irrigation	7.5	6.75	6.75	10%
Third irrigation	7.5	7.5	7.5	0
Fourth irrigation	7.5	7.5	7.5	0
Total	**40.0**	**28.1**	**28.1**	**30%**

Note: There were no water savings from wheat sown using HS over stubble burnt zero till wheat.

Electricity saved

Saving 30% of irrigation water would help save 168kWh/ha of electricity used by electric tubewells for pumping GW. Currently, the farm sector gets an unlimited supply of electricity for free for irrigation. Therefore, there is no financial benefit to farmers from any saving of electricity used for irrigation. There are likely to be considerable economic benefits to society from the electricity saved, but these have not been considered in the financial analysis.

Labour saved from reduced irrigation

A typical rice-wheat farmer in Punjab employs casual labour to meet the peak demand during both the winter and summer seasons. Farm labour is readily available from the local market for Rs10/hour.

In Punjab about 28% of the net sown area is under the canal command area, ranging from less than 1% in central districts, to 80 to 90% in the some of the south west districts of the state (Government of Punjab, 2005 and Appendix 2). The use of canal water for irrigation is much cheaper than the costs and time involved in pumping groundwater. Due to lack of information on the amount of channel water used and the charges, the value of labour saved from irrigation operations was based on the time required to irrigate using groundwater (15 hours to apply one irrigation of 7.5 cm/ha). A 30% irrigation water saving out of a total amount of 100 cm per ha would save 23.75 hours or Rs238/ha of human labour involved in irrigation operations.

3.3 Value of total benefits

The total annual financial benefits from the HS over wheat sown following conventional tillage after burning stubbles and zero tillage after burning stubbles were estimated taking into account the benefits from reduced input costs, human labour and machinery costs. The total value of the annual financial benefit from the HS was Rs.2,445-2,642 /ha over wheat sown following conventional tillage and Rs.370 - 566/ha over zero till after burning rice stubbles.

3.4 Estimating the costs of methods of wheat establishment after rice

We used contract rates to estimate the costs of using the HS and other machinery for different options of managing stubbles and sowing wheat. It is assumed that tractors and other machinery are readily available for different agricultural operations on contract basis. Full details of the operations involved and their costs are provided in Appendix 1. Mulching of stubbles and direct drilling wheat using the HS costs Rs2,163/ha. Sowing wheat with the seed-fertiliser drill after incorporation and burning of stubbles costs Rs3,600 and Rs3,500/ha, respectively. Sowing wheat with zero tillage machines after burning rice stubble is the cheapest method and costs Rs1,688/ha.

4. Other Community and environmental benefits

As indicated earlier we have focussed on the financial implications of the HS for the rice wheat systems in Punjab. However widespread adoption of the HS has important social and environmental consequences. The study has identified some significant human and animal health, other community and environmental benefits for which we have not attempted to estimate any monetary value.

4.1 Community benefits

Adoption of the HS would lead to community benefits through reduction in traffic hazards, and improved human and animal health, due to reduction in air pollution in the rice wheat belt of the state.

Reduction in traffic hazards

Thick clouds of smoke, emerging from the burning of rice stubble can engulf roads, causing accidents and blocking or slowing down traffic especially on narrow (two lane country side roads (Fig 6 and 7).

Fig 6 and 7: Air pollution from burning rice stubbles

The accidents cause loss of life and property, while the traffic delays waste time and fuel, increase transportation costs and create additional pollution from idling engines. It has been estimated that poor visibility due to smoke from stubble burning leads to 20% extra travel time (Personal communication, Assistant District Transport Officer, Sangrur, Punjab). Punjab has a total road length of around 55,000 km with more than more than 3,511 buses travelling about 1.05 million km per day plus 400,000 tractors, 100,000 trucks, 330,000 cars and 3 million scooters (Government of Punjab, 2005), so reduction in traffic delays could have significant financial and economic benefits as well as lifestyle benefits.

A preliminary analysis of the records of the Khanna police district, a small area within the rice-wheat belt, revealed that the number of accidents increased in the months of July (probably due to heavy rains) and in October-November when stubbles are burnt (Appendix 3). A more detailed study of the long term trends in accidents in different police districts of different rice growing regions would help to estimate value of loss of time, fuel and human life, productivity, and public property due to burning stubbles.

Most healthy people, including children, recover quickly from exposure to smoke and do not suffer long-term consequences. However, certain sensitive groups can experience more severe short-term and chronic effects. It appears that the same population groups that are susceptible to particles in cities are also susceptible to particles from biomass burning. These groups are: people with asthma and other respiratory disease, people with cardiovascular disease, children and the elderly. Pregnant women and unborn children are potentially susceptible, given that smoke from biomass burning contains many of the same compounds found in cigarette smoke.

Impact of smoke on human health

In Punjab, more than 60% of the population live in the rice growing areas and is exposed to air pollution due to burning of stubbles. It is estimated that burning 1 t of straw releases 3 kg particulate matter, 60 kg CO, 1,460 kg CO_2, 199 kg ash and 2 kg SO_2 (Gupta and Sahai 2005). A more detailed list of emissions from burning crop residues is given in Appendix 4. Inhaling the fine particulate matter present in the atmosphere leads to serious problems of human health, especially among children, old age people, pregnant women and people with acute asthmatic and cardio vascular problems. Inhaling of fine PM also causes lung disease, coughing, and shortness of breath, decreasing lung function (Agrawal 2006, Australian Government 2005, Canadian Lung Association web site http://www.lung.ca/protect-protegez/pollution-pollution_e.php and Lal 2006). In Punjab there are about 850,000 asthma patients, and inhaling of fine particulate matter of less than PM 2.5µ acts as an asthma trigger and aggravates symptoms (Dr A Singh, Pulmonologist, Christian Medical Collage and Hospital, Punjab). Medical records of the Civil Hospital of Jira, in the rice-wheat belt, show that, on average, there is a 10% increase in the number of patients within 20 to 25 days of the burning period every season (Pers. Comm. Dr L. Sandhu, SMO, Civil Hospital Jira).

A more detailed analysis of the composition and concentration of the particulate matter and other pollutants and their long term effects on human health and associated costs is needed.

Impact of smoke on animal health

In Punjab, people living in the countryside keep on an average 4 dairy animals per household for domestic and commercial use (Puri 2004). Inhalation of fine particulate matter also adversely affects animal health. Preliminary investigations suggest that air pollution can result in death of animals due to conversion of normal Haemoglobin (Hb) to deadly Hb due to high levels of CO_2 and CO in the blood. It may also cause corneal irritation and temporary blindness, allergic rhinitis, chronic bronchitis and bronchiolitis leading to asthma-like conditions and a potential decrease in milk yield (Pers. Comm. APS Brar, Veterinary Pathologist, H Singh, Professor of Medicine and A Singh, Assoc Prof of Veterinary, PAU Ludhiana).

4.2 Environmental benefit

Some of the key environmental benefits of adoption of the HS are as follow:

Release of CO_2 and other green house gases (GHG)

As mentioned earlier, in Punjab more than 90% of the 17Mt of rice residues are burnt each year releasing 22Mt of CO_2, 0.92Mt of CO and 0.03Mt of SO_2 per year. Mulching and zero tillage may help reduce these GHG emissions through carbon sequestrations. This needs further investigation.

Similarly, the use of the HS in wheat helps save 45 litres of fuel per ha from reduction in the use of tractors in comparison with conventional tillage. It would also help save 121 kg of CO_2, a green house gas emission in the atmosphere.

In Punjab, around 60 percent of total power generation in Punjab, is generated in the coal fired power stations (Government of Punjab, 2005). Direct estimates are not available on the CO_2 released from use of coal for generating electricity. It is estimated that the reduction in use of electricity from 30% saving of water would also lead to a saving of 161kg of CO_2 emission to the atmosphere. Also any saving of fuel due to reduction in traffic delays would lead to significant reduction of GHG emissions that needs further examination.

Reduction in loss of biodiversity

Fires in fields along the roads cause damage to the plantations of up to 3-4 m high, and other vegetation on roadsides and canal banks, and some of the small plantations are totally destroyed. This also results in a loss of biodiversity because the plantations and bushes are home to some rare varieties of birds, including the national bird, the peacock. They build their nests in bushes or trees along the roads or water channels (Punjab Pollution Control Board, 2006 Chandigarh). The adoption of the HS would not only protect the plantations and green vegetation, it would also protect the biodiversity in the state.

Decline in the watertable

Due to rice wheat cultivation, the watertable in Punjab is declining very fast and farmers are forced to use submersible pumps to pump out groundwater from deeper levels. The watertable in most of the blocks in the rice wheat belt is declining at 70-80cm/year. This is also evident from the fact that more than 30% of the tubewells have been converted from centrifugal to submersible pumps over the last 6 years. A saving of 30% of water in the direct drilled wheat would help in checking the decline in watertable.

5. Benefit cost analysis

Over the 20 year period, the NPV of the total financial benefits from adoption of the HS was Rs 9,420/ha compared to stubble burnt/zero tillage wheat, and Rs31,910/ha over the stubble burnt/ conventional tillage option.

Sensitivity analysis was used to demonstrate the effects on returns of changes in yield, savings of key inputs and changes in discount rate used in the analysis.

The NPV of the total financial benefits of the HS was most sensitive to changes in yield, followed by weedicide use, discount rate, machinery costs and less sensitive to irrigation water and nitrogen use (Table 5). For example, the net benefits almost doubled over conventional tillage and increased by five times over zero tillage with a yield increase of only 5% using the HS. If there is no reduction in herbicide use with the HS, zero tillage after burning is slightly more profitable than the HS at the same yield.

Table 5: Net present value of total financial benefits of the HS with different levels of crop yield, input savings, machinery operations and discount rate

Financial benefits of HS	NPV of benefits (Rs/ha) over Conventional	Zero tillage
1. Wheat yield increase		
- *No increase*	31,910	6,150
- *5% increase*	59,500	33,945
- *10% increase*	87,250	61,524
2. Herbicide use		
- *50% reduction*	31,910	6,150
- *No reduction*	21,415	-5,097
3. N fertiliser use		
- *With reduction*	31,910	6,150
- *No reduction*	30,325	4,576
4. Irrigation **water saving**		
- *With 30% reduction*	31,910	6,150
- *With no reduction*	28,640	6,150
5. Discount rate		
- 7% discount rate	31,910	6,150
- 10% discount rate	24,190	4,783
- 4% discount rate	44,785	9,267
-		
6. **Machinery operations**		
- 1 discing	31,910	6,150
- 2 discings	38,115	6,150

The findings of the initial financial evaluations of the HS technology suggest that the technology is financially viable for farmers, and is more profitable than conventional alternatives, especially conventional tillage. However, these evaluations assume contract provision of HS sowing services for an "average" farm. During the current phase of the project, the technology is being tested for a range of soils and farm sizes in different agro climatic regions in the state to estimate the long term impacts of some of the key variables that would help in drawing firm conclusions about the financial viability of the technology.

Due to the current institutional arrangements surrounding the rice-wheat production system of Punjab, the current costs of many of the inputs, e.g. irrigation water, electricity used for pumping ground water, diesel, fertiliser, interest on agricultural loans etc. are not fully borne by farmers. Hence, in addition to the financial benefits to farmers, the adoption of the HS technology may deliver benefits to the rest of the community. For example, there would be significant economic benefits from any reduction in the costs involved in the use of electricity (supplied free to agriculture) as a result of reduced groundwater pumping due to improved water use efficiency. Reduced demand for water may also lead to a reduction in the huge investment required to convert to submersible pumps as groundwater supplies decline. Similarly savings of fertiliser and fuel would also lead to reduction in the cost to the government of subsidies for fertiliser and fuel used in agriculture. Furthermore, there will be considerable benefits to society through the reduction in air pollution from stubble burning. A detailed economic analysis is required to estimate the full potential economic benefits from the reduction in the use of a range of inputs and from the reduced adverse environmental impacts.

6. Major constraints to adoption of the HS

Development of the HS technology is a major breakthrough in managing rice stubbles and direct drilling wheat after rice. The findings of the economic analysis presented above shows that the HS is not only financially viable; it also helps address key soil health, social and environmental issues associated with the burning of rice stubbles in Punjab. The study has identified some mechanical, technical and social constraints that may affect the adoption of the HST in Punjab. These include:

- Limited use of the HS due to small size of holdings: It involves a large capital cost to buy a HS and 45 HP tractor, the minimum power required to operate the HS. More than 66% of the rice-wheat farms in Punjab are less than 4 ha (Appendix 5). Therefore machinery purchased by small farmers would be underutilised due to its limited use on-farm.

- Capacity of the machine: With a capacity of the current model of the HS of 5 acres/day and a narrow sowing window for wheat, even the professional machinery contractors may not be able to operate the HS for more than about 30 days or 165 acres (66ha) per year resulting in poor returns on the investment on the HS. Increasing the capacity of the HS and its use in planting a wider range of crops into a wider range of residues would increase the potential annual utilisation of the machine; help make it more attractive and a commercially viable option.

- Less efficient contract arrangement: Most of the custom work in growing and harvesting crops is done by full time farmers. Due to stiff competition most farmers tend to use their machines for custom work even at very low rates. A professional machinery contractor may not be able to afford to provide machinery at the prevailing market rates and would charge higher for custom hiring of the HS. This may increase the cost of managing stubbles and direct drilling wheat compared to the other current practices of direct drilling wheat after burning stubbles.

- Lack of information on potential benefits: The initial financial evaluations of the HS technology presented above indicate that the technology is financially viable for farmers, and is more profitable than conventional alternatives. However, these evaluations were limited by limited data availability, and were only undertaken under assumptions of contract provision of HS sowing services for an "average" farm. The HS was developed recently and farmers have not yet adopted this technology. There is also a general lack of information on its long term impacts on soil fertility, crop yields, saving of machinery, labour, water and other input costs. Therefore, the implications of uncertainty for some of the key variables in the analyses have not been able to be adequately investigated, and investigations for a range of farm circumstances have not yet been undertaken. Given the expected sensitivity of the financial viability of the technology to these factors, firm conclusions about financial viability cannot yet be made.

- Limited capacity of the industry to meet demand: Dasmesh Mechanical Works, who developed this machine in collaboration with PAU, and National Agro Industries are the only manufacturer of the HS in Punjab, India. The maximum capacity is 200-250 HS per year which would not be able to meet the potential demand for the machine. The level of manufacturing capacity is a highly relevant parameter for policy makers when they are determining a feasible timetable for enforcement of the ban on residue burning.

- Lack of straw spreaders on combine harvesters in Punjab – the loose straw needs to be spread uniformly prior to using the HS. This can be done manually but this is tedious, time consuming and incurs labour costs, and spreading will be less even than can be achieved by mechanical straw spreaders. There is a need for development of a straw manager and spreader for combine harvesters, so as to eliminate the need for manual spreading of straw prior to sowing with the HS.

- Lack of machinery to form bunds in the presence of rice straw (a typical 1 acre rice field is normally divided into quarters after wheat sowing by forming small bunds to enable more even and efficient irrigation of wheat). The current machines used to form bunds do not work well in the presence of straw.

- Distorted price signals: Key features of the HS technology are its capacity to substantially reduce the input requirements of a rice-wheat production system and its capacity to reduce adverse side-effects of the production system (especially air pollution from rice stubble burning). However, prevailing institutional arrangements surrounding the rice-wheat production systems of Punjab mean that many of the financial benefits of adopting the HS technology are not received by the adopting farmers (or put differently, the current costs of following conventional farming practices are not financially borne by those farmers). Consequently, the financial incentive to change practices is much lower than in circumstances where more of the costs of conventional practices are privately recognised and borne by farmers instead of being socialised to the broader community. The range of agricultural production inputs for which farmers do not bear the full cost is quite broad, including irrigation water, electricity for pumping irrigation water, petroleum products, fertiliser, herbicides and pesticides. In addition, the benefits accruing to the community from the reduction in stubble burning related pollution include: improvements in human and animal health; reductions in traffic accidents and delays; reductions in damage to community roadside infrastructure, plantations and biodiversity; and reductions in GHG emissions. The consequences of these price distortions and broader impacts are invisible to farmers, as is evident from the findings of the financial analysis, that show only marginal benefits for farmers from the adoption of the technology (For more details see Pagan &Singh 2006).

7. Conclusions

The results of this benefit cost analysis suggest that the NPV of the total financial benefits from adoption of the HS was Rs6,150/ha over 20 years over the NPV of stubble burnt/zero tillage wheat, and Rs31,910/ha over the stubble burnt/ conventional tillage option. This is based on the conservative assumption that there were no yield increases associated with the HS in contrast to findings to date of average yield increases of around 10% (Sidhu et al. 2007a).

Sensitivity analysis indicates that the returns from the HS are highly sensitive to yield, and more sensitive to weedicide savings than to discount rate or machinery costs,, water and fertiliser savings. The net benefits were almost doubled for a 5% increase in wheat yield with the HS over the stubble burnt conventional tillage.

The study has identified some important health, community and environmental benefits from the widespread adoption of the HS. We have not yet been able to put monitory value on any of these benefits.

Although the adoption of the technology has numerous benefits as discussed above, lack of information on the long term impacts of use of the HS on soil fertility, crop yields, saving of machinery, labour, water and other input costs, may slow its adoption. Some of the other key constraints like the capital cost of farmers buying and operating their own machinery, with limited use on small holdings, together with relatively poor returns on investment for machinery contractors due to its limited use due to a relatively narrow wheat sowing window and low capacity of the machine, may also adversely affect the rate of adoption of the technology.

This financial evaluation of the HS technology indicates that the technology is financially viable for farmers, and is more profitable than conventional alternatives. However, more comprehensive financial evaluation is needed because of the preliminary nature of the estimates of benefits of many of the inputs, as the technology is new and data availability is limited. Furthermore, the impacts of the price distortion issues and the significant potential additional value of the externalities associated with the HS technology needs a detailed economic evaluation of the technology to determine a more complete valuation of the net benefits of the HS technology to society as well as to farmers.

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Appendix 1: Comparison of operations and costs of methods of wheat establishment after rice.

Particulars	Happy Seeder			Seed-Fertilizer Drill with straw incorporation			SeedFertilizer Drill after burning			Zero Till Drill after burning		
	Qty/No.	Cost per operation Rs/ac	Total cost Rs/ac	Qty/No	Cost per operation Rs/ac	Total cost Rs/ac	Qty/No	Cost per operation Rs/ac	Total cost Rs/ac	Qty/No	Cost per operation Rs/ac	Total cost Rs/ac
Stubble Shaver including 1 hr labour	-	-	-	-	-	-	1	210	210	1	210	210
Cost of burning straw (labour)	-	-	-	-	-	-	1	15	15	1	15	15
Pre Sowing Irrigation[A]	-	-	-	1	25	25	1	25	25	1	25	25
Preparatory Tillage												
-Ist Discing	-	-	-	1	300	300	1	300	300	-	-	-
-2nd Discing	-	-	-	1	200	200	-	-	-	-	-	-
-Tyne harrows	-	-	-	2	200	400	2	200	400	-	-	-
-Planking	-	-	-	2	100	200	2	100	200	-	-	-
Straw Spreading	2	10	20.00	2	10	20	-	-	-	-	-	-
Sowing	1	750	750.00	1	200	200	1	200	200	1	300	300
Extra seed (kg/acre)	-	-	-	-	-	-	-	-	-	5	12	60
Bund making[B]	1	75	75.00	1	75	75	1	50	50	1	50	50
Rodent Control	1	20	20.00	1	20	20	-	-	-	1	15	15
TOTAL			865.00			1440			1400			675

[A] Electricity is 100% subsidized
[B] Differences in cost of bund making is due to presence of rice straw.

Appendix 2: Area (thousand ha) irrigated by canal and tube wells in Punjab

Year	Govt. Canals	Private Canals	Wells	Other sources	Total	% to Net sown area
1960-61	1,173 (58%)	7 (0.4%)	829 (41%)	11 (0.5%)	2,020 (100%)	54
1970-71	1,286 (45%)	6 (0.2%)	1,591 (55%)	5 (0.2%)	2,888 (100%)	71
1980-81	1,430 (42%)	-	1,939 (57%)	13 (0.4%)	3,382 (100%)	81
1990-91	1,660 (43%)	9 (0.2%)	2,233 (57.%)	7 (0.2%)	3,909 (100%)	93
2000-01	1,002 (25%)	-	3,017 (75%)	2 (0.1%)	4,021 (100%)	94
2002-03(P)	1,148 (29%)	-	2,880 (71%)	7 (0.2%)	4,035 (100%)	95

Source: Statistical Abstract of Punjab, Chandigarh 2006

Appendix 3: Road accidents in the Police district Khanna in Punjab from 2003-05

		Accidents					
			2003	2004			2005
	Month	No.	%	No	%	No	%
1	January	13	9	10	7	7	4
2	February	13	9	10	7	5	3
3	March	16	11	11	7	8	5
4	April	7	5	10	7	10	6
5	May	9	6	16	11	18	11
6	June	10	7	15	10	14	8
7	July	10	7	9	6	25	15
8	Aug	13	9	13	9	14	8
9	Sept	15	10	14	9	13	8
10	Oct	10	7	18	12	17	10
11	Nov	17	11	13	9	21	13
12	Dec	19	13	11	7	16	10
	Total	**152**		**150**		**168**	

Source: Punjab State Police Department, Chandigarh 2006

Appendix 4: List of major pollutants emitted during crop residue burning

Category	Pollutants	Source	Notes
Particulates	SPM (PM100)	Incomplete combustion of inorganic material veg fragments ashes, soil particles on burnt soot	Course fraction do not travel long distance contain ashes and soil dust
	RPM (PM10) FPM PM 25	Condensation after combustion of gases and incomplete composition of orifice matter	Tpt upto great distance have greater impact
Gasses	CO	Incomplete combustion of organic matter	Tpt upto great distance
	NO_2, N_2O	Oxidation of N2 in air at high temp.	Reactive species concence deercase with distance
	O3	Secondary pollutant, form due to Nitrogen Oxide and Hydrocarbon	Tpt over great distance
	Formaldehyde	Due to incomplete combustion	Low concentration have great impact
	CH/Benzen	Incomplete combustion organic material	Even low concentration cause serious damage
	PAHs	Incomplete combustion of organic matter mostly benzopyrene	Even low concentration cause serious damage

Source: Clear Air: Environmental Governance-4; Indira Gandhi Institute of Research, 2001
SPM = small particulate matter PM = particulate matter. FPM fine particulate matter, PM25

Appendix 5: Number of operational land holdings in Punjab. (2000-01)

Size Classes (ha)	Average Size of Land Holding (ha)	Number (000)	%age	Area (000 ha)	%age
Below 1	0.6	123	12	77	2
1-2	1.4	173	17	242	6
2-4	2.7	328	33	876	22
4-10	5.8	301	30	1731	43
10 and Above	15.2	72	7	1096	27
Total	4.0	997	100	4022	100

Source: Statistical Abstract, Chandigarh, Punjab,, 2005.