Sustainability Implications of Burning Rice-and Wheat-Straw in Punjab

B S Sidhu
O P Rupela
V Beri
P K Joshi

Yields from the rice-wheat cropping system in the Indo-Gangetic plain are declining despite the increasing use of chemical fertilisers. Crop residues are important components of soil fertility management, but are burnt in some areas such as Punjab state. Not only does this mean a loss of nutrients but also causes environmental pollution (and the associated health effects); the production of substantial quantities of carbon dioxide, a greenhouse gas can adversely affect the environment. Limited published data suggest that rice-straw can be converted to high value manure of a quality better than that of farmyard manure (FYM). Its use along with chemical fertilisers should not only sustain present level of crop yields but also increase it It would, however, require policy interventions perhaps both at the levels of the state and central governments.

INTRODUCTION

RICE and wheat have become the most prominent crops in the present Punjab since the mid 1960s. The total area under rice increased from 0.24 million ha in 1960-61 10 2.16 million ha in 1995-96, and covered approximately 54 per cent area cropped during rainy season. The average productivity of rice has also increased substantially from 1.l86 kg ha^{-1} in 1966-67 to 3.132 kg ha^{-1} in 1995 96, Similarly, the area under wheat has increased from 1.14 million ha in 1960-61 to 3.22 million ha in 1995-96 (77 percent of the total area during the post-rainy season). Average productivity increased from 901 kg ha^{-1} in 1950-51 to 3,884 kg ha^{-1} in 1995-96. The rapid expansion of area under rice and wheat could be attributed to the availability of high-yielding, short-duration varieties, agronomy packages to match the varieties, and support from the government in developing irrigation and well structured market and price policies [Gill 1994]. As a result of these increases in area and productivity, Punjab has surplus grains and contributes significantly to food security in India. Its share in India's foodgrain pool in 1995-96 was 37 per cent in rice and 59 per cent in wheat.

Rice-wheat is the most exhaustive cropping system, depending heavily on soil nutrients and water. In one cycle of rice-wheat, nutrient removal (N, P_2O_5 and K_2O) is about 501.6 kg ha^{-1} to produce 4 t of wheat and 5.21 of rice. Despite intensive use of inputs, yields have stagnated particularly of rice [Nambiar and Ghosh 1984]. It may also be mentioned that in the early stages of the technology dissemination of rice in Punjab, some farmers obtained yield as high as 9 t ha^{-1} [Nambiar and Abrol 1989] but currently only a few farmers cross 7t ha^{-1} [Chatha et al 1994]. Reduced soil fertility is often stated as one of the most important reasons among others. This is despite the fact that use of chemical fertilisers in Punjab has increased substantially over the years. During 1960-61 only 5,000 t of nitrogenous and no phosphatic and potassic fertilisers were used. This increased to 1.01 million t of nitrogenous, 2,56,0001 of phosphatic and 15,000 t of potassic fertilisers during 1994-95 [Statistical Abstract of Punjab 1995].

Before the mid-1960s, the two important organic sources of nutrients were farmyard manure (FYM) and legumes. Both were almost completely replaced by chemical fertilisers. It is common knowledge that the majority of the rice-growing farmers in Punjab burn rice-straw, a potential source of nutrients and organic carbon vital for soil health [Dalal and Myers 1986], Ever increasing use of chemical fertilisers, which are convenient and cheap (due to subsidies) substituted the organic sources of nutrients. Preparation and use of organic nutrients, for example F Y M involves bulk handling of materials, seems unhygienic and is laborious. Legumes were formerly a significant component of the different cropping systems in Punjab. In 1960-61, legume area was 0.90 million ha and area under major cereals was 2.17 million ha. By 1994-95 this changed to 0.095 million ha (about 10-fold reduction) under legumes and 5.81 million ha under major cereals. Legumes and organic manures are regarded as important restorers of soil health [Jiao *1*983; Abrol and Palaniappan 1988], partly because of their ability to acquire nitrogen from air. The question often raised is whether sustainability of soil can be improved by incorporating organic sources of nutrients, in the absence of legumes. To understand and document the ground reality and to learn farmers' perceptions on the use of these sources of nutrients, a survey was conducted. This paper reports findings of the survey and discusses their implications on sustainability of the rice-wheat cropping system.

THE SURVEY

A special questionnaire was designed to facilitate dialogue with the sample farmers. It included several modules, e g, a section on farmers' economic resources/status, their perceptions about on-farm available biological sources of nutrients (e g, crop residues; preparation and use of FYM) and pattern of chemical fertilisers use.

The study covered 11 of the 14 districts and 48 of the 137 blocks of Punjab dominated by rice-wheat cropping system. Efforts were made to ensure that each of the 11 districts was represented adequately. A total of 237 farmers surveyed for the study was randomly selected such that not more than 10 were taken from a block. Some farmers who were outliers were dropped from the sample during analysis. The survey was conducted during September-October 1996. Simple tabular analysis was carried out to understand various issues related to existing crop residue use and its future prospects.

Area sampled in each district covered 198 to 258 ha (except Bhatinda, 43 ha) in the total area of 2,383 ha owned by the surveyed farmers. About 99.5 per cent area of the surveyed farmers was irrigated. Cotton-wheat was the major cropping system in Bhatinda and therefore only four farmers were included in the study.

It was difficult for the sample farmers to provide accurate information on the quantity of rice- and wheat-straw produced. But they did assess grain yield of different

crops in previous years, which was used to assess quantities of straw. The ratio of grain/straw of rice and wheat in different experiments ranged between 1.5 and 1.7 [Larson et al 1978; Bhardwaj 1995; Beri and Sidhu 1996], in this paper, we used the ratio of 1:1,5 for both crops. Each farmer interviewed for the study, represented a farming unit. It included the land a farmer had on lease.

CHARACTERISING SURVEYED FARMERS

The average size of land holdings of the sample farmers was 10.04 ha (Table 1). About 51 per cent of the surveyed families owned 2 to 8 ha land Panning in the state is mechanised which is reflected by the fact that 79 per cent of the sample farmers owned a tractor Tractor ownership was lowest in Sangrur and highest in Fatehgarh district. Only 6 per cent farmers possessed combines used for harvesting rice and wheat (but a large number of farmers used combines, see farther paragraphs and sections). About 14 per cent of the sample farmers used shredders for cutting the standing stubble after combine harvesting of rice. ' Cattle resources of the farmers were also recorded to estimate the availability of dung for preparing FYM, Farmers with < 2 ha land owned an average of 6.7 cattle while those with more than 20 ha land owned 15.8 cattle (Table 2), The highest number of cattle per farmer was found in Kapoorthala (14.7), and the lowest in Bhatinda (6.8). These statistics perhaps indicate farmers' perception towards diversification of agriculture.

CROP RESIDUES AND THEIR END USE

Of the total area owned by the sample farmers, 75 per cent was under rice and 80.7 per cent under wheat. Across districts, area under rice ranged from 44.9 per cent in Bhatinda to 85.5 percent in Kapoorthala and that under wheat ranged from 69.6 per cent in Julan dhar to 90 3 percent in Sangrur (Table 3), The percentage of the area under rice and wheat was higher than the state averages (53,8 percent under rice and 76.6 per cent under wheat in 1995-96), This was mainly due to the fact that rice-wheat farmers were chosen for the survey.

Combines and reapers were mostly used for harvesting both rice and wheat (88.6 per cent of rice and 56.6 percent of wheat). The rice area harvested by combine varied from 54.2 per cent in Amritsar to 99.4 per cent in Ferozepore. In case of wheat it varied from 37.3 per cent in Bhatinda to 65.4 per cent in Julandhar (Table 3). According to the surveyed farmers, the reasons for greater use of combine for rice harvest were, (i) high labour cost for manual harvesting and threshing, (ii) no significant income generating alternative use of rice residues, (iii) combine harvesting allows rapid field preparation for the next wheat, (iv) use of rice residues as cattle feed was uncommon for fear of reduced milk yield, (v) despatch of harvested rice to market straight from the field.

Total quantity (14,035 t) of rice-straw of the sample farmers ranged from 43.8 t farmer[1] in Julandhar to 73.11 farmer [1] in Patiala district with an average of 59.2 t farmer[1]. The quantity of wheat-straw ranged from 42.3t farmer[1] in Gurdaspur to 64.6 t farmer[1] in Amritsar (Table 4).

TABLE 1: CHARACTERISATION OF THE AREAS SURVEYED IN DIFFERENT DISTRICTS OF PUNJAB

(Percentage)

	Total Area Surveyed (ha)	Average[1] Holding (ha)	Land Holding Size (ha) <2	2-4	4-8	8-20	>20	Per Cent[2]
Amritsar	233.1	11.7	0.7	8.0	5.5	36.9	48.7	9.6
Bhatinda	43.8	10.9	0	6.5	18.7	74.8	0	1.8
Faridkot	258.0	9.6	1.1	8.7	13.9	48.3	27.9	10.8
Fatehgarh	209.4	11.0	0.8	4.9	21.3	39.2	33.8	8.8
Ferozepore	196.5	12.3	1.2	3.1	9.8	51.5	34.4	8.3
Gurdaspur	207.6	8.7	0.8	9.0	17.7	72.5	0	8.7
Julandhar	232.7	9.3	0	5.4	25.6	56.8	12.2	9.8
Kapoorthala	224.2	9.8	0.5	7.4	24.7	30.5	36.8	9.4
Ludhiana	234.1	9.0	0.7	8.0	21.1	49.1	21.1	9.8
Patiala	246.8	10.7	0.6	3.2	22.2	34.6	39.3	10.4
Sangrur	296.8	9.9	0.7	10.3	13.8	57.5	17.7	12.5
Over all mean		10	1.4	3.0	6.3	14.0	28.8	
Per cent[2]			0.7	6.9	17.5	48.2	26.6	

Notes: 1 Operational holding of the surveyed farmers, includes leased area.
2 Per cent of the total surveyed area, 2383 ha.

TABLE 2: CATTLE OWNED BY THE SURVEYED FARMERS

(Percentage)

District	No of Cattle Per Farmer	Land Holding Class (ha) <2	2-4	4-8	8-20	>20	Per Cent[1]
Amritsar	13.2	1.1	25.1	8.0	36.1	29.7	10.1
Bhatinda	6.8	–	18.5	29.6	51.9	–	1.0
Faridkot	8.7	4.7	16.2	25.1	41.3	12.8	9.0
Fatehgarh	10.9	4.3	8.2	23.2	31.9	32.4	7.9
Ferozepore	14.6	8.2	7.3	21.4	53.2	9.9	8.9
Gurdaspur	10.4	2.8	7.6	17.6	72.0	–	9.6
Julandhar	8.7	–	13.4	62.3	31.8	2.8	8.3
Kapoorthala	14.7	30.9	14.2	32.2	46.7	5.9	13.0
Ludhiana	11.4	4.7	15.9	27.5	38.6	13.2	11.3
Patiala	10.7	2.9	12.2	34.3	27.8	22.9	9.4
Sangrur	9.9	2.7	19.2	21.5	47.1	9.4	11.4
Average	11.0	6.7	6.8	10.3	13.7	15.8	
Per cent1		3.1	14.3	26.1	43.2	13.3	

Notes: 1 Per cent of total number (2607) of cattle.

TABLE 3: PER CENT AREA (OF THE SURVEYED FARMERS) UNDER RICE AND WHEAT AND THAT HARVESTED BY COMBINE

District	Rice Area District Total	Rice Area Harvest by Combine[3]	Wheat Area District Total	Wheat Area Harvest by Combine[3]
Amritsar	84.5	54.2	84.7	50.5
Bhatinda	44.9	93.8	70.1	37.3
Faridkot	58.5	97.2	73.6	46.7
Fatehgarh	86.2	76.7	87.7	58.4
Ferozepore	71.6	99.4	76.2	63.2
Gurdaspur	73.8	85.1	83.7	49.6
Julandhar	66.0	89.1	69.6	65.4
Kapoorthala	85.5	92.7	79.7	56.0
Ludhiana	72.3	96.1	75.6	38.9
Patiala	83.0	88.3	86.0	50.6
Sangrur	82.4	96.7	90.3	51.6
Per cent	75.7[1]	87.2[2]	80.7[1]	52.5[2]

Notes: 1 Per cent of total (2383 ha) surveyed area.
2 Per cent of the area grown to rice or to wheat.
3 Area harvested by combine out of the area under a given crop in the district.

It was observed that majority (82 percent) of the farmers burnt rice-straw. But only 48 per cent fanners burnt the wheat-straw. It may be noted that wheat-straw is a common dry fodder for animals in Punjab.

Fanners sold wheat-straw while rice-straw was given free to requesters, particularly for fodder. In addition, rice-straw was sold to paper mills where it was used along with more preferred raw materials, and to a rice-straw based power plant of 10 MW capacity at Jalkheri, Patiala (the only one in the state, operationalised in late 1993 with initial cost of Rs 65 crore). The paper mills procured rice-straw at a rate of Rs 200 to 300t^{-1} at the mill premises. The manually harvested rice-straw was purchased by poor landless families at a price ranging from Rs 700-1,200 ha^{-1}.

The farmers generally sold wheat-straw after making chaff. The sale price of wheat chaff generally varied between Rs 2,500 and Rs 3,700 ha^{1}. In some years it could fetch up to Rs 5,000 ha-1 in off season. It was evident from the survey data (Table 4) that rice and wheat were harvested largely by combine. Combines left 20-55 cm high stubble of rice and 20-45 cm high stubble of wheat. The height of the stubble was governed by the degree of lodging and moisture content in the straw, At harvesting, rice-straw generally has higher moisture content than that of wheat, therefore combines were adjusted such that only the panicles of rice were harvested. This was done to prevent moist rice-straw from choking the drum of the combine. Generally, dry wheat-straw does not choke the drum. Lodged crops were invariably harvested manually. Chaff was thrown/discarded as combines move and being spread all over a field, was expensive to collect. Wheat residues were needed as fodder not only in Punjab but also in the neighbouring states. Specially designed combines were also used, these had attached trolley for collecting wheat-straw for use as fodder.

The cost of combine harvesting of crops varied with time of the year, its availability and degree of lodging of the crop. The rates generally varied from Rs 600 to Rs 1,500 ha^{-1} for rice and Rs 600 to Rs 750 for wheat. The rates for wheat harvesting were generally lower than for rice, because wheat fields can be harvested more quickly.

BURNING CROP RESIDUES

Burning of leftover wheat stubble is easy, as it is completely dry at harvest in April/May (atmospheric humidity 35-39 per cent). Rice stubble is difficult to burn because rice stems and the fields are wet at harvest in September/October, when humidity ranges from 60 to 78 per cent. Also, farmers are in a hurry to prepare land for sowing the wheat crop in November. After the wheat harvest, fields are generally kept fallow for at least 50 days. Almost half of the surveyed fanners cut the stubble of rice with a shredder This hastened drying and helped effective burning of straw when ignited. Without shredding, it took 5-8 days for drying before burning. Also, in an unshredded field 5-20 per cent of the rice-straw was left unburned depending upon its moisture content. The farmers did not use any fuel to aid burning of rice-stubble.

Burning of rice* and wheat-straw is not only a loss of nutrients but also an environmental hazard. Therefore, researchers have studied the effect of incorporation of rice- and wheat-straw in long-term experiments for at least seven years and found that it significantly improved soil health but not yield of the subsequent crops [Sidhu and Beri 1989; Beri et al 1992; Beri et al 1995], Surveyed farmers indicated that incorporating straw into soil involved additional cost for labour, irrigation, and extra tillage; and less than 1 per cent of the farmers incorporated rice- and wheat-straw. One of the farmers who incorporated rice-straw 20 days before sowing wheat stated that it increased yield of the following wheat by about 250 kg ha^{-1},

PREPARATION AND USE OF FARM YARD MANURE

Application of organic manures is considered very useful for improving the physical condition of the soil, besides providing plant nutrients, though in small quantities [Biswas et al 1971, Kumar et al 1992, Biswas and Benbi 1997]. These facts are not new to farmers and all the surveyed farmers had milch or draught animals, and produced F Y M from their dung.

No special efforts were made by the sample farmers to prepare F Y M . Seventy-five per cent of the farmers deposited the daily yield of dung along with barn and kitchen wastes in a corner of their house or on the roadside. The remaining farmers prepared specific pits or used available low lying areas in the vicinity of their house to deposit these organic materials. These heaps of organic materials stayed for at least six months to a year before their contents were transported for field application. On examination, most heaps were found to have raw dung at the top of heaps and well decomposed manure at the base and centre as reported by Motavalli and Anders (1991). None of the farmers followed scientifically recommended

TABLE 4: RICE- AND WHEAT- STRAW PRODUCED AND THEIR END-USE BY SURVEYED FARMERS

District	Quantity (t)	End Use[1] in Different Districts (Per Cent of Total Produced by Farmers)				
		Fodder	Incorp	Burnt	Sold	Misc
Rice straw						
Amritsar	1532.3	18.2	0.0	49.4	19.6	9.4
Bhatinda	185.0	0.0	0.0	100.0	0.0	0.0
Faridkot	1346.9	0.4	0.0	97.6	0.8	1.3
Fatehgarh	1336.8	8.1	0.0	78.0	12.3	1.6
Ferozepore	954.5	3.3	8.8	68.1	1.0	18.8
Gurdaspur	1135.7	12.9	1.7	62.5	1.7	20.6
Julandhar	1094.0	3.2	0.0	88.4	2.8	4.7
Kapoorthala	1401.9	5.7	1.7	88.0	0.0	4.4
Ludhiana	1408.0	1.9	0.0	94.9	0.5	2.7
Patiala	1656.8	11.7	0.0	81.5	5.9	0.9
Sangrur	1942.7	0.4	0.0	94.8	1.9	2.8
Per cent[2]		6.5	0.9	81.4	4.8	5.8
Wheat straw						
Amritsar	1291.1	39.9	0.0	54.2	5.9	0.0
Bhatinda	210.0	41.1	0.0	33.4	25.5	0.0
Faridkot	1168.7	54.6	0.0	40.1	5.3	0.0
Fatehgarh	1092.4	28.4	0.0	45.2	26.4	0.0
Ferozepore	822.2	25.4	0.0	69.2	0.0	5.4
Gurdaspur	1014.6	49.1	2.4	48.5	0.0	0.0
Julandhar	985.8	35.6	0.0	64.4	0.0	0.0
Kapoorthala	1075.1	43.5	0.0	53.7	2.8	0.0
Ludhiana	1205.6	54.3	0.0	37.5	6.1	2.1
Patiala	1169.6	38.7	0.0	43.6	15.3	2.4
Sangrur	1544.6	48.0	0.0	39.5	11.6	0.9
Per cent[2]		42.6	0.2	48.2	8.1	1.0

Notes: 1 Information on use of rice- and wheat-straw as fuel, for composting, and for rope making was also collected. Only 0.5 to 0.6 per cent farmers used rice-straw as fuel in Gurdaspur and Julandhar only, 0.1 to 3.6 per cent farmers made ropes from rice-straw for tying canes of sugarcane crop. No farmer prepared compost from rice- or wheat -straw. Incorp = incorporated in the soil; Misc = collected by or given to landless poor families.

2 Per cent of the total 139941 of rice- and 11580 t of wheat-straw produced by the surveyed farmers.

method(s), as described by Gaur (1984) or amended the contents during composting.

Almost all (99 per cent) the sample farmers applied F Y M to their fields. Eighty- eight per cent of the sample farmers applied it in the rainy season irrespective of application in other seasons. About 8 per cent applied it only in the post-rainy season and 14,2 per cent applied it in both rainy and post-rainy seasons. In the rainy season, F Y M was applied predominantly to rice, maize, fodder crops and vegetable crops (at locations near cities) that are reported to be more responsive to F Y M than wheat (Meelu 1981, Gill and Meelu 1983]. The other apparent reason was that farmers had free time during the fallow period after the wheat harvest During rest of the year, fields are covered by standing crops. In the post-rainy or summer seasons preferred crops for application of F Y M were non-legume fodder, potato, sunflower and sugarcane. Wheat was the least preferred crop,

None of the farmers applied F Y M to a field every year. About 74 per cent of rainy, *15* percent of post-rainy, and 60 per cent of summer applications of F Y M were made once in every three to four years to a given field. About 7.6 per cent fanners took more than four years for repeat application to a field in the rainy season and 10.9 per cent farmers in the post-rainy season. The predominant rate of F Y M application WAS 10-15 trolleys (1 trolley = approximately 3,000 kg wet mass) ha^{-1} All farmers used the same method of application, F Y M was transported in tractor trolleys to the field. Small heaps of one basket full (about 15 kg wet manure) were deposited all over a field at approximately 3 m distance between heaps, as the tractor was moving. These heaps were further spread manually (using spades)just before land preparation. The time gap between depositing of F Y M in field and its incorporation at land preparation is a subject for study, as exposure to the hot sun would affect manure quality.

The.average holding of the sample farmers was 10 ha and there were 11 animals per family. If one animal produced a trolley of dung in a year a family will have approximately 11 trolleys per year. The application will repeat approximately after 10 years, if F Y M was applied at the rate of 10 trolleys ha^{-1}. But this was not the case in practice. Farmers invariably applied F Y M to fodder crops first and only the excess, if any, was applied to other crops. It was not the field but the crop, which determined application of F Y M. Thus repeat sowing of a crop in a given field dictated the repeat application of FYM.

It was apparent that farmers were well aware of the importance of F Y M and about 80 per cent of the farmers faced shortages of F Y M. But only 21.6 per cent of them purchased F Y M from available sources. Limited quantities of F Y M were available for sale with poor landless families owning cattle and from 'Gaushalas' (charity dairies). The price varied between Rs 50-100 per trolley. The price was ex-house and purchasers had to transport it to their fields.

USE OF INORGANIC FERTILISERS

The recommended rates of fertilisers for rice include 120 kg nitrogen and 30 kg each of phosphorus (P_2O_5)and potassium (K_2O) ha^{-1}. However, where rice follows wheat and the recommended dose of phosphorus is applied to wheat, rice may not receive P_2O_5. The recommended rate of fertilisers for 'wheat is 120 kg N. 60 kg P_2O_5 and 30 kg K_20 ha^{-1}. Application of phosphorus and potash is recommended only if soil tests have indicated their need [Meelu 1979; Gill and Meelu 1982]. Data on nitrogen and phosphours applied to rice and wheat area owned by the respondent farmers are shown in Table 5. It was interesting to note that 32 per cent area received close to the recommended level (120 kg ha^{-1}) of N for rice and 61 per cent for wheat. Sixty six per cent area received higher than the recommended dose of nitrogen for rice and only 2.3 per cent received less than the recommended dose. It was also observed that 37 per cent of the area owned by the respondents also received higher and 1.6 per cent area received a lower rate of nitrogen than that recommended for wheat. Over-application of nitrogen is known to cause lodging in these crops [Brady 1995). In sample farmers this trend was more prevalent in rice than in wheat.

As regards phosphorus, 8.8 percent area received the recommended level of phosphorus to rice and 92.6 per cent to wheat. Because about 90 per cent area under rice follows wheat and about 92.6 of the surveyed area received optimum dose of phosphorus for wheat, only 5.6 per cent area received an over-dose of phosphorus to rice and 5.1 per cent to wheat. Wheat is known to respond well to phosphorus in Punjab [Sahota et al 1971; Gill and Meelu 1983].

Discussions with farmers revealed that urea was the major source of nitrogen, and diammonium phosphate was the source of phosphorus. Farmers did not weigh fertilisers at application, and instead approximated the quantities to be applied by using full or half bags (1 bag = 50 kg), It seemed that this sometimes resulted in over-application. Over-application was more in the case of nitrogen than in phosphorus, perhaps due to the prohibitive

TABLE 5: PER CENT OF AREA OF FARMERS RECEIVING DIFFERENT RATES OF NITROGENOUS AND PHOSPH ATIC FERTILIZERS IN DIFFERENT DISTRICTS OF PUNJAB

	N (kg ha^{-1}) Application Rates				P_2O_5 (kg ha^{-1}) Application Rates				
District	<100	100-135	135-160	>160	Nil	1-25	25-50	50-75	>75
Rice									
Amritsar	1.0	53.7	43.9	1.4	95.0	5.0	0	0	0
Bhatinda	0	74.8	6.5	18.7	74.8	0	25.2	0	0
Faridkot	0	13.7	22.4	63.9	61.9	29.0	0	6.1	3.0
Fatehgarh	10.5	28.4	12.2	49.0	74.9	4.8	13.5	6.8	0
Ferozepore	3.9	39.9	47.2	9.1	36.7	34.7	20.4	8.2	0
Gurdaspur	1.5	23.6	17.9	57.1	89.0	2.6	7.4	1.1	0
Julandhar	0	20.6	12.3	67.2	79.7	5.4	8.5	6.4	0
Kapoorthala	7.3	38.9	40.3	13.5	62.3	0	24.1	13.7	0
Ludhiana	3.6	47.2	34.5	14.7	78.0	0	16.7	5.4	0
Patiala	0	37.0	28.9	34.2	96.7	0	0	3.3	0
Sangrur	0	20.3	39.3	40.3	81.4	15.0	0	3.6	0
Per cent area of 231 surveyed farmers	2.3	31.6	27.7	38.3	76.6	9.1	8.8	5.3	0.3
Wheat									
Amritsar	0.9	84.9	0	14.2	0	0.9	0	99.2	0
Bhatinda	42.0	32.8	0	25.2	0	0	42.0	58.0	0
Faridkot	0	49.5	0	50.5	0	0	0	100.0	0
Fatehgarh	0	32.7	18.5	48.9	0	0	0	81.5	18.6
Ferozepore	0	83.1	0	16.9	0	0	14.1	85.9	0
Gurdaspur	0	88.6	1.3	10.2	0	0	2.0	98.0	0
Julandhar	0	43.7	0	56.4	0	0	0	100.0	0
Kapoorthala	7.3	91.4	0	1.3	0	0	0	100.0	0
Ludhiana	2.2	67.5	23.5	6.8	0	0	0	74.4	25.6
Patiala	0	55.8	0	44.2	0	2.1	0	95.0	3.0
Sangrur	0	41.1	8.7	50.2	0	0	0	88.2	11.8
Per cent area of 231 surveyed farmers	1.6	60.9	4.4	33.1	0	0.3	2.0	92.6	5.1

cost of phosphatic fertilisers (N-urea, Rs 7.22 kg^{-1}; $p_2 0_5$ SSP, Rs 17 kg^{-1} and K, O-muriate of potash, Rs 8 kg^{-1}). None of the surveyed farmers applied potash either to wheat or to rice. Most Punjab soils have a pre-dominance of potash-rich clay minerals [Meelu and Ruymbeke 1969; Sidhu and Bhangu 1995]. Therefore, crops respond only in low K soils. Extensive soil analysis for available potassium of rice-wheat soils will be needed to detect such soils.

Due to the extensive practice of rice-wheat rotation, micronutrient deficiencies are appearing in Punjab soils. In particular, zinc deficiency has become very common in rice, and to a lesser extent in wheat. Therefore, 60 kg zinc sulphate ha^{-1} is recommended [Nayyar et al 1990] for rice only. Zinc application to wheat can be skipped if followed by rice. The recommended quantity is sufficient for two to three years. It was observed during the survey that not even a single farmer used zinc sulphate for wheat but almost alt applied it to rice. About 71 per cent of the respondents used 25 kg zinc sulphate ha^{-1} and 23 per cent did not use any zinc sulphate to any crop. Instead of applying the recommended 60 kg zinc sulphate ha^{-1} after two to three years, farmers preferred to apply 25 kg zinc sulphate ha^{-1} to rice every year.

QUANTITY OF RICE- AND WHEAT-STRAW BURNT ANNUALLY

There were no authentic data on quantities of rice-straw and wheat-straw burnt by farmers in Punjab. Previous estimates of farmers burning 75 per cent rice- and 20 percent wheat-straw annually were based on very limited travel and discussions with farmers [Beri et al 1995]. The data from this survey is more authentic, since it covered a wider area and large number of farmers for such assessments. Quantities of rice- and wheat-straw burnt in the different districts of Punjab are given in Table 6, which is based on the yield data of rice and wheat in 1995-96. Of the total quantity of 9.9 million t of rice-straw about 8 million t was burnt. Of the 18.9 million t of wheat-straw about 9 million t was burnt by farmers. This would have resulted in 28.2 million t of carbon dioxide ($C0_2$), a greenhouse gas responsible for global wanning. In addition, the suspended particles as smoke are a health hazard for the local population. Also, significant quantities of valuable nutrients would have been lost due to burning. One of the major nutrients 'N' lost during burning was estimated (assuming both rice- and wheat-straw contained 0.5 per cent N) to 85,506 t yr^{-1}. At the subsidised price of Rs 7 2 2 kg^{-1} N this was calculated to Rs 617.3 million (sUS $ 17 .7 million, 1 $=Rs 35 during survey in 1996). This is a substantial loss that can be prevented.

SUSTAINABILITY IMPLICATIONS AND LIKELY SOLUTIONS

India's population is predicted to cross the I billion mark by the year 2000 [Brown 1981]. The ever-increasing population is a potential threat to food security. Researchers and policy-makers are exploring new avenues to not only sustain the present level of productivity but also increase it. Introduction of legumes into rice-wheat cropping system can break the cereal-cereal cycle and help the low fertility fatigued soil of Punjab. Based on discussions with farmers and given the present policies (minimum support price, subsidised fertiliser) of the state and central governments it seems highly unlikely that farmers wilI take up legumes in a significant way to replace either of the two cereals. It is widely accepted that yields of most legumes will be less stable than those of rice and wheat because they are threatened by more diseases and insect pests than the two cereals. Even if these technical weaknesses are removed, the government policies on prices make rice and wheat more remunerative than for example, chickpea and pigconpea. Thus the outputs of previous and ongoing research on legumes are unlikely to reach farmers* fields to help sustain production of rice and wheat in the near future.

Farmers appreciate the value of F Y M. But it is preferentially applied to vegetables and fodder crops, maize and rice where its beneficial effects seem more visible. Wheat was the least preferred crop for F Y M application. In addition. farmers do not use the scientific method of composting, recommended at least 40 years ago, when significant efforts and money were spent to popularise it. Thus quality of their F Y M may be significantly lower (and needs to be studied) than that prepared scientifically. Some farmers reported seedling deaths due to heat produced following application of FYM. This is scientifically explicable and indicates incomplete decomposition of dung. Lack of proper decomposition seemed due to

TABLE 6; ASSESSMENT OF QUANTITIES OF RICE- AND WHEAT-STRAW BURNT ANNUALLY BY PUNJAB FARMERS
(based on 1995/96 yield statistics)

District	Grain Production ('000 t)		Quantity ('000 t) of Straw[3] Produced Annually		Quantity ('000 t) of Straw Burnt Anually[4]			Annual Loss of N (t) through Burning of Straw[5]		
	Rice	Wheat	Rice	Wheat	Rice	Wheat	Total	Rice	Wheat	Total
Amritsar	843	1338	1265	2007	625	1088	1712	3123	5439	8562
Bhatinda	144	833	216	1249	216	417	633	1080	2087	3167
Faridkot[1]	575	1410	863	2115	842	848	1690	4209	4240	8450
Fatehgarh	265	355	398	533	310	241	551	1550	1203	2754
Ferozepore	559	1648	839	2472	571	1711	2282	2855	8553	11408
Gurdaspur	462	749	693	1123	433	545	978	2166	2724	4890
Julandhar	501	611	752	917	664	590	1254	3322	2951	6273
Kapoorthala	256	415	384	622	337	334	672	1690	1671	3361
Ludhiana	743	1081	1115	1622	1058	608	1665	5288	3040	8329
Patiala	695	998	1043	1497	850	652	1502	4248	3263	7512
Sangrur	1091	1687	1637	2530	1551	1000	2551	7757	4998	12754
Hoshiarpur[2]	167	627	251	941	203	453	657	1020	2267	3286
Ropar	123	274	185	411	150	198	348	751	991	1741
Mansa	144	592	216	888	176	428	604	879	2140	3019
Total	6568	12618	9852	18927	7988	911	17101	39937	45568	85506

Notes: 1 Includes area of Moga and Muktsar (new districts). 2. Includes area of Nawan Shehar(new district).
3 Data of grain production was multiplied by 1.5 to calculate quantity of straw produced annually (see Material and methos for reasons).
4 Mean percent straw burnt by the sample farmers in the II surveyed districts from Table 4 was used to obtain this data. For the last three districts values of 81.4 for rice and 48.2 for wheat (i e, means of the II districts) were used because these were not included in the survey.
5 In our assesments N per cent in rice and wheat straw ranged from 0.43 per cent to 0.63 per cent. An average of 0.5 per cent N was used to calculate N loss during burning.

the fact that handling it was not considered dignified, while application of chemical fertilisers was convenient and a status symbol. Under such a scenario it is highly unlikely that farmers will decompose rice- or wheat-straw into manure, particularly because the process requires more technical knowledge and better facilities than composting dung. Continuous incorporation of wheat-straw for at least seven years to a given plot of land did not significantly increase yield of the following maize [Sidhu and Beri 1989], Such a practice is unlikely to be followed by farmers who find it very convenient to burn and clear the field for the next crop. Burning has been found to boost growth of the following wheat [Sidhu and Beri 1985, Sidhu and Beri 1989] at least for 30-40 days, after which the effect disappears. Burning of diseased stubble has long been recommended, but large-scale burning as being done in Punjab is obviously harmful and should be stopped.

It is feasible to compost rice-straw (and perhaps wheat-straw) into valuable manure [Sidhu et al 1997] on a research scale, Rupela (1995) opined that it should be possible for a young person in a village with basic schooling, to learn the process. If the government provided policy support (training and financial support), such a person could set up a village level enterprise to purchase .straw from farmers in the village, compost it and sell the product to farmers. However, feasibility study needs to be done. If successful, this should help return part of the nutrients to the field in addition to providing organic carbon (considered valuable for sustainable and good soil health). Also, it should help increase use efficiency of chemical fertilisers by different crops and help solve the problem of pollution (of air by burning of rice-straw, and of drinking water by excessive use of fertiliser and its potential leaching into aquifers). This should prove an important step to produce sustainably high yields of rice and wheat in Punjab and other parts of India.

[Gurbux Singh of the Punjab Agricultural University, Ludhiana for assistance in collection of data through interviewing the farmers, Ch Vijay Kumar, M Asokan and P V S Prasad of ICRISAT Potancheru for assistance in analysing the data, and T J Rego for comments to improve the manuscript.]

References

Abrol 1 P and $ P Palaniappa (1988); Green Manure Crops in Irrigated and Rainfed Low-Land Rice-Based Cropping Systems in South Asia[1] in *Green Manure in Rice Farming* pp 71-82 IRR1, Los Banos, Philippines,

Banger, K C S Shankar, K K Kapoor, K Kukreja and M M Mishra (1989); Preparation of Nitrogen and Phosphorus-Enriched Paddy-Straw Compost and Its Effect on Yield and Nutrient Uptake by Wheat (Triticum aestivum L)', *Biology and Fertility of Soils.* 8:339-42,

Beri. V and B S Sidhu (1996): Management of Crop Residues for Better Environment' in B D Kansal, G S Dhaliwal and M S Bajwa (eds). *Agriculture and Environment,* pp 179-98, National Agriculture Technology Information Centre, Ludhiana, India.

Beri, V.B S Sidhu, G S Bahl and A K Bhat (1995): Nitrogen and Phosphorus Transformations as Affected by Crop Residues Management Practices and Their Influence on Crop Yields', *Soil Use Management,* 11:51-54.

Beri. V, B S Sidhu, A K Bhat and B Singh (1992): ' Nutrient and Soil Properties as Affected by Management of Crop Residues' in Beri et al (eds), *Proc Intern Symp on Nutrient Management and Sustained Productivity,* pp 133-35, Department of Soils, PAU, Ludhiana, India,

Bharadwaj, K K R (1995); 'Recycling of Crop Residues, Oilcakes and Other Plant Products in Agriculture" in H L S Tandon (ed), *Re cylcing of Crop, Animal. Human and Industrial Wastes in Agriculture,* pp 9-30, Fertiliser Development and Consultation Organisation, New Delhi,

Biswas C R and D K Benbi (1997): *Dynamics of Physical, Chemical and Biological Propertiies of Soil and Yield in a Long-Term Fertiliser Experiment.* Research Bulletin No 3/97, Department of Soils, Punjab Agricultural University, Ludhiana 141004, India.

Biswas, T D. B L Jain and S C Mandal (1971): 'Cumulative Effect of Different Levels of Manures on the Physical Properties of Soil', *J Ind Soc Soil Sci,* 19:31-37.

Brady, N C (1995); *The Nature and Properties of Soils,* (Tenth edition), Prentice Hall of India. New Delhi.

Brown, L R (1981): 'World Populations Growth, Soil Erosion and Food Security', *Science* 214:995-1002.

Chatha, I S , Joginder Singh and S S Grewal (1994): 'A Study on Adoption of Rice Technology in Punjab', *Bulletin Department of Economics and Sociology,* Punjab Agricultural Univeristy. Ludhiana.

Dalai, R C and R J Myer (1986): 'Long-Term Trends in Fertility of Soils under Continuous Cultivation and Cereal Cropping in Southern Queensland It Total Organic Carbon and Its Rate of Loss from Soil Profile'. *Ausi J Soil Res* 24: 281-81

Gaur, A C (1984):A *Manual of Rural Composting,* FAO/UNDP Regional project RAS/75/004, Document no 15, p 102.

Gill. H S (1994): 'Sastailiability Issues Related to Rice-Wheat Production System in Asia', R S Paroda, T Woodhead and R B Singh (eds),*sustainability of Rice- Wheat Production Systems in Asia,* pp 36-60, FAO Regional Office, Bangkok, Food and Agriculture Organisation of the United Nations, Thailand.

Gill, H S and O P Meelu (1982): Studies on the Substitution of Inorganic Fertilisers with Organic Manures and Their Effect on Soil Fertility in Rice-Wheat Rotation.'. *Fertiliser Research,* 3:303-14.

-(1983); "Studies on the Utilisation of Phosphorus and Causes for Its Differential Response of Rice-Wheat Rotation', *Plant and Soil* 74:211-22.

Government of Punjab (1991): "Statistical Abstracts of *Punjab',Economic and Statistical Organisation,* publication no 687, p 763.

- (1995): 'Statistical Abstracts of Punjab' *Economic and Statistical Organisation,* publication no 753, p 819.

Jiao, B (1983): "Utilisation of Green Manure for Raising Soil Fertility in China', *Soil Science,* 135:65-69.

Kumar, K, O P Meelu, Y Singh and B Singh (1992): 'Effect of Continuous Application of Organic Manures on the Physical Properties of Soil in Rice-Wheat Cropping System[1], *IRRI News,* L 17(4):16-I7.

Larson. W E, R F Holt and C W Carlson (1978): 'Residues for Soil Conservation' in W R Oschwald, M St elly, D M Kral and J H Nanseef (eds),*Crop Residue Management Systems,* pp 1-15, A AS A Special Publication no 31, Madison, Wisconsin 53711.

Meelu, O P (1979): 'Soil Test for NPK and Crop Response to NPK Application', *Fertiliser News,* 24(8):22-26.

-(1981): 'Integrated Use of Fertiliser and Manures in Cropping Sequences[1], *Indian Farming.* October, 75-79.

Meelu, O P and M Y Ruymbeke (1969): 'Mineralogical Composition of the Clay Fractions of Soils Representing Different Agroclirrmtic Regions of Erstwhile Punjab State', *Plant Science,* 1:164-72.

Motavalli, P P and M M Anders (1991): 'Management of Farmyard Manure in India's Semi-And Tropics: Fanner Perceptions and Practice', *Production Agronomy Progress Report I,* Resource Management Programme, International Crops Research Institute for the Semi-And Tropics, ICRISAT, Patancheru 502 324, p 101.

Nambiar, K K M and I P Abrol (1989): 'Long-Term Fertiliser Experiments in India[1], *Fertiliser News,* 34(4): 11-20.

Nambiar, K K M and A B Gosh (1984): 'Highlights of Research of Long-Term Fertiliser Experiments in India (1971-82)', *LIFE Reserch Bulletin,* no 1, IARI, New Delhi, p 100.

Nayyar V K, P N Takkar, R L Bansal, S P Singh, N P Kaur and U S Sadana (1990): 'Micronutrient in Soils and Crops of Punjab',, *Research Bulletin,* P 146-xiv, Department of Soils, Punjab Agricultural University, Ludhiana,

Rupela, O P (1995): 'Composting Crop Residues and Plant Litter - A Business Enterprise' in R K Behl, A L Khurana and R C Dogra (eds), *Plant Microbe Interactions in Sustainable Agriculture,* pp 184-97, CCS Haryana Agricultural University, Hisar. India.

Sahota, N S. S Singh, O P Meelu and M D Joshi (1971): 'Response of Wheat to P in Soils Varying in Available P Status', *Fertiliser News,* 16(9):43-45.

Sidhu, B S and V Beri (1985): 'Recycling of Crop Residues in Agriculture ' in *Proceedings, Soil Biology Symposium.* February, pp 49-53. Haryana Agricultural University, Hisar, Haryana.

-(1989): 'Effect of Crop Residue Management on the Yields of Different Crop and on Soil Properties', *Biological Wastes,* 27:15-27.

Sidhu, P S and S S Bhangu (1995): 'Mineralogy of Potash in Soils of Punjab' in *Proceedings of Symposium Use of Potash in Punjab Agriculture,* pp 24-33. Department of Soils, Punjab Agricultural University, Ludhiana.

Sidhu, B S, O P Rupela, S Gopalakrishnan and V Beri (1997): 'Searching Alternatives to Burning Rice Straw', Beri V, V K Dilawari and M S Bajwa (eds), *Proceedings (volume 2) of the Third Agricultural Science Congress,* pp 29-30, March 12-15, 1997, Punjab Agricultural University and National Academy of Agricutural Sciences, Ludhiana 141 004. Punjab.