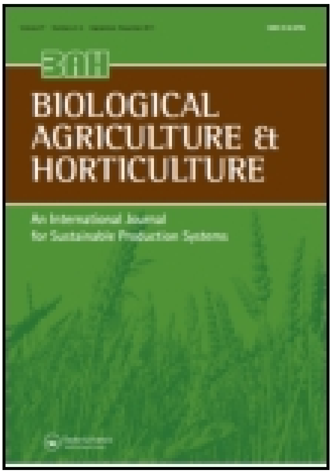
This article was downloaded by: [190.151.168.196]
On: 21 October 2014, At: 03:05
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tbah20

Effect of cropping systems and crop residue incorporation on production and properties of soil in an organic agroecosystem

M. R. Davari [a] , S. N. Sharma [b] & M. Mirzakhani [c]

[a] Department of Agriculture , Payame Noor University , I.R of Iran

[b] Division of Agronomy , Indian Agricultural Research Institute , New Delhi , 110 012 , India

[c] Islamic Azad University, Farahan Branch , I.R. of Iran

Published online: 24 Oct 2012.

To cite this article: M. R. Davari , S. N. Sharma & M. Mirzakhani (2012) Effect of cropping systems and crop residue incorporation on production and properties of soil in an organic agroecosystem, Biological Agriculture & Horticulture: An International Journal for Sustainable Production Systems, 28:3, 206-222, DOI: 10.1080/01448765.2012.735005

To link to this article: http://dx.doi.org/10.1080/01448765.2012.735005

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing,

Biological Agriculture & Horticulture
Vol. 28, No. 3, September 2012, 206–222

Effect of cropping systems and crop residue incorporation on production and properties of soil in an organic agroecosystem

M.R. Davari[a]*, S.N. Sharma[b] and M. Mirzakhani[c]

[a]*Department of Agriculture, Payame Noor University, I.R of Iran;* [b]*Division of Agronomy, Indian Agricultural Research Institute, New Delhi-110 012, India;* [c]*Islamic Azad University, Farahan Branch, I.R. of Iran*

Field experiments were conducted at the Indian Agricultural Research Institute, New Delhi, India, in 2006–2007 and 2007–2008 to study the effects of rice-wheat (RWCS)) and rice-wheat-mungbean (RWMCS) cropping systems and crop residue incorporation on the productivity, protein yield, energy output, and chemical, physical, and biological properties of soil. RWMCS had higher productivity, protein yield, and energy output than RWCS. Available N, populations of bacteria, fungi, and actinomycetes, microbial biomass, and CO_2 evolution in soil were also higher in RWMCS than in RWCS. The incorporation of crop residue increased the productivity, protein yield, energy output, soil organic C, soil Kjeldahl N, Olsen's P, neutral 1 N NH_4OAC extractable K, population of bacteria, fungi, actinomycetes, microbial biomass, and CO_2 evolution in soil. RWMCS, along with residue incorporation, was the best and is recommended for higher productivity and resilience in soil health as an alternative to an organic RWCS.

Keywords: available N; bulk density; energy output; microbial biomass; rice; wheat

Introduction

The rice (*Oryza sativa*)-wheat (*Triticum aestivum*) cropping system (RWCS) occupies about 28.8 Mha in India, Pakistan, Nepal, Bangladesh, and China (Prasad 2005). These five countries comprise 43% of the world's population on 20% of the world's arable land (Singh and Paroda 1994). In India, RWCS occupies 12 Mha and contributes about 31% of the total food grain production (Kumar and Yadav 2006). Similarly, in China, RWCS occupies about 13 Mha (Jasdan and Hutchaon 1996) and contributes about 25% of the total cereal production in the country (Lianzheng and Yixian 1994). Thus, RWCS is of considerable significance in meeting Asia's food requirements. However, the practice of following a cereal-cereal cropping system on the same piece of land over many years has led to soil fertility deterioration and questions are being raised about its sustainability (Duxbury et al. 2000; Ladha et al. 2000; Prasad 2005). Therefore, efforts were made to find alternative cropping systems. Sharma et al. (1995b) and Sharma and Prasad (1999) recommended that growing a short duration mungbean after wheat and incorporating its residue before succeeding rice made rice-wheat-mungbean (RWMCS) more productive, remunerative, and soil recuperative than the traditional RWCS.

Organic farming of Basmati rice-based cropping systems is another alternative for sustainability of crop production and natural resources. Moreover, there is a great demand

---

*Corresponding author. Email: mrdavari@gmail.com

ISSN 0144-8765 print/ISSN 2165-0616 online

http://dx.doi.org/10.1080/01448765.2012.735005
http://www.tandfonline.com

for organically grown food in European and Middle Eastern countries, resulting in two to two and a half times higher prices for organic produce. Organic farming often has to deal with a scarcity of readily available nutrients in contrast to inorganic farming, which relies on soluble fertilizers. The aim of nutrient management in organic systems is to optimize the use of on-farm resources and minimize losses (Kopke 1995). Maximum use of crop residues should be made as these can contribute toward building soil fertility (Jasdan and Hutchaon 1996). Rice and wheat straw have great potential to supply plant nutrients in organic farming of RWCS. The straw in the system accounts for about 35 to 40% of N, 10 to 15% of P, and 80 to 90% of K removal by these crops (Sharma and Sharma 2004). Thus, incorporation of straw results in the recycling of a sizable amount of plant nutrients. However, there is great difficulty in using the plant residue of cereals due to higher C:N ratio. Hence, there is an urgent need to develop a suitable technology to use crop residues in organic farming. It is necessary to mix the plant residues of cereals with well-decomposed farmyard manures or plant residues of legumes to narrow the C:N ratio so as to overcome the adverse effect of immobilization of plant nutrients. Sharma et al. (1995a) and Sharma and Prasad (1999) reported that incorporation of mungbean residue was at par with *Sesbania* green manure in RWCS. The present investigation was therefore undertaken to compare of RWCS and RWMCS and to study the effect of crop residue incorporation on the productivity, protein yield, and energy output of the cropping systems and on the properties of soil.

Materials and methods

Experimental site and soil

Field experiments were conducted during July and June of 2006–2007 and 2007–2008 at the Indian Agricultural Research Institute, New Delhi, India (28° 38′ N, 77° 11′ E, 228.6 m above mean sea level). The soil of the experimental field was a sandy clay loam (typic Ustochrept) in texture having 52.06% sand, 22.54% silt, and 25.40% clay. The soil was medium in organic C (5.2 mg kg^{-1} soil), low in available nitrogen (73.1 mg kg^{-1} soil), medium in available phosphorus (8.42 mg kg^{-1} soil) and available potassium (187 mg kg^{-1} soil), and had a pH 8.16 (Table 1).

Table 1. Mechanical and chemical characteristics of soil of the experimental field.

Property	Value
Mechanical composition	
Sand (%)	52.06
Silt (%)	22.54
Clay (%)	25.40
Textural class	Sandy clay loam
Chemical composition and physical properties	
pH (1:2.5 soil:water ratio)	8.16
Electrical conductivity (dS m^{-1} 25°C)	0.79
Cation exchange capacity (C.mol kg^{-1} soil)	14.73
Organic C (g kg^{-1} soil)	5.20
Total Kjeldahl N (mg kg^{-1} soil)	580
0.5 M $NaHCO_3$ extractable P (mg kg^{-1} soil)	8.42
Neutral 1 N NH_4OAC extractable K (mg kg^{-1} soil)	187
Bulk density (Mg m^{-3})	1.50
Field capacity at 1/3 atmospheric tension (%)	24.57

Table 2. Chemical composition of crop residues.

	2006–2007			2007–2008		
Composition	Rice	Wheat	Mungbean	Rice	Wheat	Mungbean
Total N (mg kg^{-1})	4700	3900	15000	5000	4100	15200
Total P (mg kg^{-1})	680	490	1100	700	500	1200
Total K (mg kg^{-1})	14600	15600	4400	14650	15700	4500
Organic C (mg kg^{-1})	408000	400000	401000	410000	403000	403000
Fe (mg kg^{-1})	434.23	349.80	849.56	437.41	372.97	876.21
Zn (mg kg^{-1})	100.52	29.89	69.13	105.09	34.67	72.04
Mn (mg kg^{-1})	58.23	73.69	79.65	60.69	78.52	88.62
Cu (mg kg^{-1})	40.02	16.85	22.23	40.67	17.43	23.04

Experimental design and treatments

The experiment was laid out in a strip plot design with three replications. The treatments consisted of two cropping systems containing rice (*Oryza sativa*)-wheat (*Triticum aestivum*) (RWCS) and rice-wheat-mungbean (*Vigna radiata*) (RWMCS) in rows, and two crop residue management practices, with no residue and residue incorporation, in columns. The treatments were continued throughout the two years of study in the same plots.

Cropping systems

In Northern India, there are three growing seasons: rainy from July to November, winter-spring from November to April, and spring-summer from March–April to June. In RWCS, rice was grown during the rainy season, followed by wheat during the winter–spring season, and the field was kept fallow during summer. In RWM, rice was grown during the rainy season, wheat during the winter, and mungbean during the spring–summer season.

Crop residue

In the no residue treatment, the entire above-ground biomass of each crop was harvested and removed from the plots, whereas in the residue incorporation treatment, only grain

Table 3. Total dry matter, organic C, total Kjeldahl N, total P, and total K recycled through crop residue incorporation under different cropping systems during two years.

Cropping systems	Dry matter (Mg ha^{-1})	Carbon (Mg ha^{-1})	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
2006–2007					
RWCS	14.2	5.7	61.7	8.5	213.1
RWMCS	17.8	7.1	114.9	12.4	228.7
Mean	16.0	6.4	88.3	10.5	220.9
2007–2008					
RWCS	16.0	6.5	72.9	5.9	216.6
RWMCS	19.7	8.0	128.2	14.0	233.0
Mean	17.9	7.3	100.6	11.8	224.8
Total of 2 years					
RWCS	30.2	12.2	134.6	14.4	429.7
RWMCS	37.5	15.1	243.1	26.4	461.7
Mean	33.9	13.7	188.9	20.4	445.7

Note: RWCS = rice-wheat cropping system; RWMCS = rice-wheat-mungbean cropping system.

was harvested and the residue of each crop each year was incorporated in the soil before sowing of the succeeding crop. This means that rice residue was incorporated for wheat, wheat residue for rice in RWCS, while in RWMCS, rice residue was incorporated for wheat, wheat residue for mungbean, and mungbean residue for rice. Before incorporation, the residue of each crop each year was weighed and analysed for carbon, nitrogen, phosphorus, and potassium using the procedures described by Prasad et al. (2006). The quantity of residue and nutrients added through it are given in Tables 2 and 3. Incorporation of crop residue in RWCS resulted in recycling of 12.2 Mg ha^{-1} organic C, 134.6 kg ha^{-1} Kjeldahl N, 14.4 kg ha^{-1} total P, and 429.7 kg ha^{-1} total K ha^{-1} in two years of study, whereas incorporation of crop residue in RWMCS resulted in recycling of 15.1 Mg ha^{-1} organic C, 243.1 kg ha^{-1} Kjeldahl N, 26.4 kg ha^{-1} total P, and 461.7 kg ha^{-1} total K.

Field techniques

During spring–summer, the plots under RWCS were kept fallow and received no fertilizer. The plots under RWMCS were irrigated and tilled at an optimum moisture level. A packet of *Rhizobium* sp. and PSB culture was poured into a sticker solution and mixed well. The inoculum thus prepared was sprinkled uniformly over seeds and mixed simultaneously. Mungbean variety Pusa Visha was seeded at a uniform row spacing of 30 cm in the first week of April each year. Two irrigations, at 25 and 45 days after sowing (DAS), were given. The crop was grown to maturity. The matured pods were manually picked and the residue was incorporated into the soil in plots having crop residue treatments. During the rainy season, the field was flooded with water and puddled with a tractor drawn offset disc harrow. The rice variety, Pusa Basmati 1, was transplanted in mid-July with two or three seedlings of 21 to 25 days of age hill^{-1} at a spacing of 20 × 10 cm. After completing the layout, farm yard manure (FYM) equivalent to 60 kg N ha^{-1} (Table 4) was evenly broadcast on the surface of the plots. Manual transplanting of rice by labourers facilitated the incorporation of FYM. Multani mitti-based blue green algae (BGA) containing four micro-organisms, *Aulosira fertilissima, Nostoc muscorum, Tolyparthrix tenuis*, and *Anabaena variabilies*, was broadcast uniformly at 1.5 kg ha^{-1} in the flooded plots 20 days after transplanting. Rice grain and straw were harvested in the first week of November.

Table 4. Chemical and physical composition of organic manure.

Composition	2006–2007		2007–2008	
	Rice	Wheat	Rice	Wheat
Total N (mg kg^{-1})	6100	6000	6200	6100
Total P (mg kg^{-1})	2700	2500	2500	2600
Total K (mg kg^{-1})	3100	3300	3000	3200
Organic C (mg kg^{-1})	139400	141000	139800	142500
Fe (mg kg^{-1})	20.85	22.35	21.89	22.94
Zn (mg kg^{-1})	39.85	38.72	39.95	40.03
Mn (mg kg^{-1})	11.85	10.94	12.05	11.67
Cu (mg kg^{-1})	2.71	2.53	2.79	2.81
C:N ratio	22.85	23.50	20.54	23.36
pH	7.18	7.19	7.21	7.20
Bulk density (g cm^{-3})	0.76	0.79	0.73	0.75
Porosity (%)	71.4	70.2	72.5	71.5

In residue incorporation plots, the straw was brought back to the field after threshing the grain, spread uniformly and incorporated with a tractor drawn disc plough. After the harvest of rice, the field was irrigated and, at optimum soil moisture, the FYM equivalent to 60 kg N ha^{-1} (Table 4) and crop residue were uniformly spread on the plots having this treatment and then incorporated with a tractor drawn heavy disc. After this the field was disked and planked twice. The sticker solution was prepared by dissolving 200 g jaggery in 250 ml water. Packets of strains of *Azotobacter chroococcum* specific to wheat and phosphate solubilizing bacteria (*Pseudomonas striata*) were prepared in the sticker solution and mixed well. The inoculum thus prepared was sprinkled uniformly over the seeds and mixed simultaneously. The treated seeds were dried in the shade before sowing. Wheat variety HD 2643 was sown in the third week of November. Cellulotic culture containing four fungi, *Aspergillus awamori, Trichoderma viride, Phanerochcete chrysosporium*, and *Aspergillus wolulens* at 600 g t^{-1} was spread over the crop residue in plots having crop residue treatments.

Soil sampling and chemical, physical, and biological analysis

Soil samples (0–20 cm depth) were collected from the experimental field before the start of the experiment and analysed for soil particle composition (Piper 1950), organic C, total Kjeldahl N, 0.5 M $NaHCO_3$ extractable P, neutral 1 N NH_4OAC extractable K, and pH using the procedures described by Prasad et al. (2006); data are given in Table 1. Again, after completing each cycle of different cropping systems, soil samples (0–20 cm depth) for each plot were collected and analysed for organic C, total Kjeldahl N, 0.5 M $NaHCO_3$ extractable P, and neutral 1 N NH_4OAC extractable K. At the end of three cycles of different cropping systems, the soil (0–20 cm) was also analysed for the population of bacteria, fungi, and actinomycetes using the serial dilution-agar plate procedure as described in Cappuccino and Sherman (1999). Bacteria were enumerated on nutrient agar (Subba Rao 1977), fungi on Rose Bengal (Ottow and Glathe 1968), and actinomycetes on Ken Knight's medium (Subba Rao 1977). Microbial biomass was also determined at the end of two cycles of different cropping systems by the fumigation method of Jenkinson and Ladd (1981). A soil corer was used to sample soil from two depths (0–15 and 15–30 cm) for an analysis of the soil's physical properties. Soil samples were dried in an oven at 105°C for 48 h. Bulk density (Mg m^{-3}) was calculated by dividing the weight of the dried soil by the volume of the core used (Veihmeyer and Hendrickson 1948). Porosity was derived from bulk density (BD) according to the formula % Porosity (P) $= [1\text{-BD/PD}] \times 100$, where PD is the particle density.

Rice equivalents, protein yield, and energy output

The productivity of rice-based cropping systems was calculated in terms of rice equivalent (RE) by using the expression:

$$\text{Rice equivalents}(\text{Mg ha}^{-1}) = \text{Ya} \times \text{Pa}/\text{Pr} \qquad \text{(Equation 1)}$$

where Ya is the economic yield of crop a (other than rice) in Mg ha^{-1}, Pa is the unit price of the economic produce of crop a, and Pr is the unit price of rice grain in Indian Rupees Mg^{-1}. Since the data on rice equivalents are subject to variation in commodity prices, which differ from country to country, protein yield per ha and energy output per ha were also computed to compare the cropping systems from the human and animal nutrition viewpoint. The protein content in rice grains was obtained by multiplying N concentration

Table 5. Effect of residue incorporation (RI) and removal (RR) on economic yield of rice-wheat (RW) and rice-wheat-mungbean (RWM) cropping systems.

	Economic yield (Mg ha^{-1})											
	Rice			Wheat			Mungbean			Rice equivalent		
Cropping system	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean
2006–2007												
RW	4.2	4.4	4.3	3.3	4.1	3.7	–	–	–	7.2	8.1	7.7
RWM	4.3	4.5	4.4	3.5	4.1	3.8	0.7	1.0	0.9	8.8	10.0	9.8
Mean	4.3	4.5	–	3.4	4.1	–	–	–	–	8.0	9.1	–
LSD ($p = 0.05$)												
Cropping system (CS)		NS			NS			–			1..0	
Residue (R)		NS			−0.29			0.07			NS	
CS × R		NS			NS			–			NS	
2007–2008												
RW	4.4	5.2	4.9	4.3	4.7	4.5	–	–	–	8.3	9.5	8.9
RWM	5.0	5.8	5.4	4.5	5.2	4.9	0.8	1.1	1.0	10.6	12.5	11.6
Mean	4.7	5.5	–	4.4	5.0	–	–	–	–	9.5	11.0	–
LSD ($p = 0.05$)												
Cropping system (CS)		0.48			NS			–			1.7	
Residue (R)		0.69			0.33			0.08			0.6	
CS × R		0.58			NS			–			1.0	
Mean over two years												
RW	4.3	4.8	4.6	3.8	4.4	4.1	–	–	–	7.8	8.8	8.3
RWM	4.7	5.2	5.0	4.0	4.7	4.4	0.8	1.1	1.0	9.8	11.5	10.7
Mean	4.5	5.0	–	3.9	4.6	–	–	–	–	8.8	10.2	–
LSD ($p = 0.05$)												
Cropping system (CS)		0.26			NS			–			1.1	
Residue (R)		NS			0.41			0.09			0.7	
CS × R		0.41			NS			–			1.1	

Note: LSD = least significant difference; NS = non-significant.

of grain by 5.95 (Juliano 1985), whereas the protein content in grain/seed of other crops was calculated by multiplying N concentration with a factor 6.25. The protein yield of different crops was calculated by multiplying their protein concentration by grain/seed yield. The energy output was calculated by multiplying energy content of grain/seed of different crops, as obtained by Singh et al. (1996), with their yield.

Statistical analysis

For treatment comparisons in the field experiments, an *F* test was used, following the procedures of factorial randomized block design (Cochran and Cox 1957). A least significant difference (LSD) was computed to determine statistically significant treatment differences.

Results

Productivity

In both years, RWMCS gave significantly higher (27 to 30%) rice equivalents than RWCS (Table 5). The grain yield of rice, which was similar in the two cropping systems, was significantly influenced by the crops grown during the winter and the spring–summer season. RWMCS, having summer mungbean, a legume, produced significantly more rice than RWCS. This increase in rice grain yield was mainly due to the summer mungbean.

Overall, residue incorporation increased the yield of wheat and mungbean in both years and of rice in the second year. The interaction between cropping systems and crop residue was significant in the case of rice yield and rice equivalent yield of cropping systems in the second years of study. In this year, incorporation of residues significantly increased yields of rice and mungbean in RWMCS and the rice equivalent value in both RWCS and RWMCS.

Protein yield

There was no significant difference in protein yield of rice and wheat in different cropping systems in the first year, whereas in the second year, rice in RWMCS gave a significantly higher protein yield than rice in RWCS (Figure 1). Residue incorporation had no

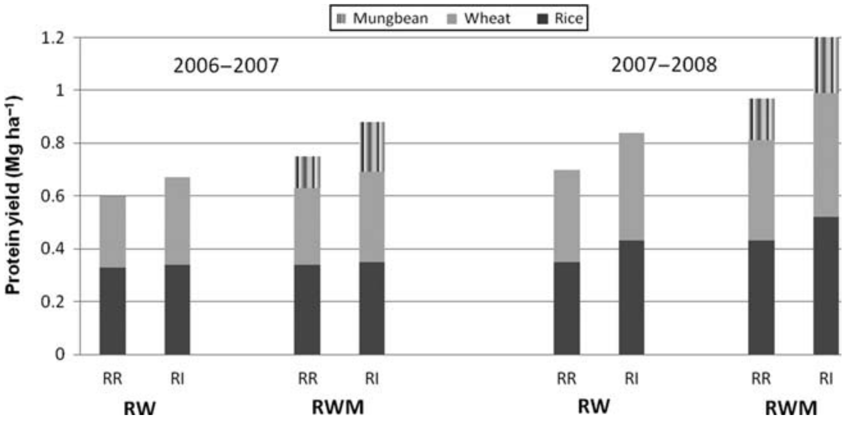


Figure 1. Effect of residue incorporation on protein yield under rice-based cropping systems (RR = residue removed; RI - residue incorporated; RW = rice-wheat cropping system; RWM = rice-wheat-mungbean cropping system).

significant effect on protein yield of rice and wheat in the first year of study, whereas in the second year, residue incorporation gave a significantly higher protein yield of rice and wheat than the control. Interaction between cropping system and crop residue was significant only in the second year of study.

During the spring–summer season, residue incorporation significantly increased the protein yield of mungbean in two years which was also reflected in the mean protein yield of mungbean over the two years. As regards total protein yield, RWMCS produced significantly more protein than RWCS in the two years of study. This was mainly due to the protein contribution of mungbean. Residue incorporation also significantly increased the total protein yield of a cropping system in two years. The significant interaction between cropping system and crop residue found in the last year indicated that residue incorporation significantly increased total protein yield in RWMCS but not in RWCS.

Energy output

The energy output of the rice crop was significantly higher in RWMCS than in RWCS in the second year of study (Figure 2). This difference was also reflected in mean energy output over two years of study. The energy output of rice was not affected significantly by residue incorporation and the interaction between cropping system and crop residue was also not significant.

Residue incorporation significantly increased energy output of wheat and mungbean in the two years of study. Regarding total energy output of a cropping system, RWMCS resulted in significantly higher energy output than RWCS. Residue incorporation also significantly increased energy output of a cropping system. Interaction between cropping system and crop residue indicated that residue incorporation significantly increased energy output only in RWMCS in the last year of study.

Chemical properties of soil

Cropping systems had no significant effect on organic C, 0.5 M $NaHCO_3$ extractable P, and neutral 1N NH_4OAC extractable K in the two years of study, whereas Kjeldahl N content in soil was significantly higher under RWMCS than under RWCS in both years of

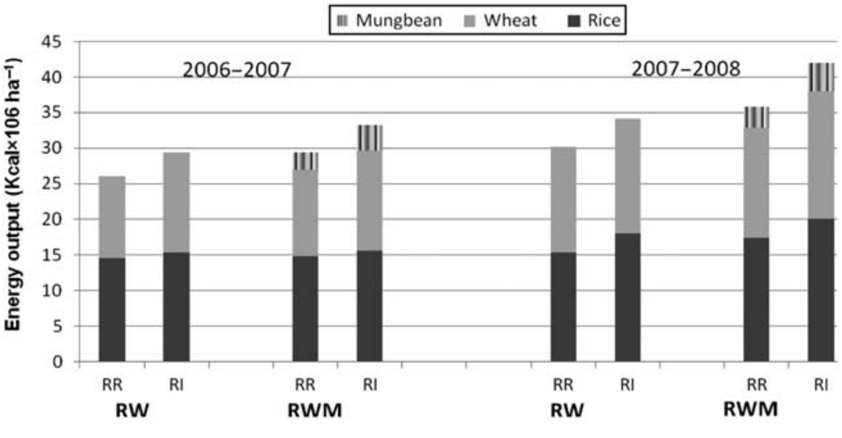


Figure 2. Effect of residue incorporation on energy output in rice-based cropping systems (RR = residue removed; RI = residue incorporated; RW = rice-wheat cropping system; RWM = rice-wheat-mungbean cropping system).

Table 6. Effect of residue incorporation on chemical properties of soil after completion of each cycle of different rice-based cropping systems.

	Organic C			Kjeldahl N			0.5 M $NaHCO_3$ extractable P			1N NH_4OAC extractable K		
	(g kg^{-1} soil)			(mg kg^{-1} soil)			(mg kg^{-1} soil)			(mg kg^{-1} soil)		
Cropping system	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean
2006–2007												
RW	5.65	6.28	5.97	6.35	70.2	669	8.6	9.1	8.9	195	223	209
RWM	5.73	6.45	6.10	698	780	739	8.8	9.5	9.2	204	234	219
Mean	5.69	6.37	–	667	741	–	8.7	9.3	–	200	229	–
LSD ($p = 0.05$)												
Cropping system (CS)			NS		61.2			NS			NS	
Residue (R)			0.32		43.2			0.53			5.6	
CS × R			0.58		NS			NS			NS	
2007–2008												
RW	6.08	6.75	6.42	789	911	850	8.8	9.4	9.1	197	227	212
RWM	6.21	6.93	6.57	875	998	937	9.1	9.9	9.5	207	241	224
Mean	5.92	6.50	–	8832	955	–	9.0	9.7	–	202	234	–
LSD ($p = 0.05$)												
Cropping system (CS)			NS		78.3			NS			NS	
Residue (R)			0.44		46.8			0.38			5.9	
CS × R			0.66		61.4			0.48			8.1	

Note: RR = residue removed; RI = residue incorporated; RW = rice-wheat cropping system; RWM = rice-wheat-mungbean cropping system; LSD = least significant differences; NS = non-significant.

study (Table 6). The incorporation of crop residue significantly increased organic C, Kjeldahl N, 0.5 M $NaHCO_3$ extractable P, and neutral 1 N NH_4OAC extractable K content in soil in the two years of study (Table 6).

Interaction between cropping system and crop residue was significant in the two years in the case of organic C and in the last year in the case of total Kjeldahl N, 0.5 M $NaHCO_3$ extractable P, and 1 N NH_4OAC extractable K. The incorporation of crop residue had no significant effect on organic C content in soil in the case of RWCS, whereas in the case of RWMCS, residue incorporation significantly increased organic C content in the soil. Similarly, residue incorporation had no significant effect on total Kjeldahl N in the case of RWCS, whereas in the case of RWMCS, residue incorporation significantly increased total Kjeldahl N. In the case of Kjeldahl N content in soil, cropping systems did not differ significantly when residue was not incorporated, whereas when residue was incorporated, RWMCS recorded significantly higher Kjeldahl N content in soil than RWCS.

Biological properties of soil

There was a significant effect of cropping system on the biological properties in soil, and numbers of bacteria, fungi, and actinomycetes were significantly greater under RWMCS than under RWCS (Table 7). Residue incorporation significantly increased the microbial population in the soil. The interaction between cropping system and crop residue was also significant. The number of bacteria in the soil was significantly higher under RWMCS than under RWCS when residue was not incorporated. As regards fungi, there was no significant difference between different cropping systems when residue was not incorporated. On the other hand, when residue was incorporated, RWMCS resulted in significantly more fungi than RWCS. Similarly, RWMCS gave significantly more actinomycetes than RWCS without residue incorporation, whereas with residue incorporation, cropping systems did not differ significantly with respect to the number of actinomycetes in the soil.

Both microbial biomass and CO_2 evolution in the soil were significantly greater under rice-wheat-mungbean cropping system (RWM) than under rice-wheat cropping system (RW) (Table 8). The incorporation of residue increased both microbial biomass and CO_2

Table 7. Effect of residue incorporation on microbial population in soil after completion of two cycles of rice-based cropping systems.

	Bacteria			Fungi			Actinomycetes		
	(cells $\times 10^6$ g^{-1} soil)			(cells $\times 10^4$ g^{-1} soil)			(cells $\times 10^4$ g^{-1} soil)		
Cropping system	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean
RW	4.8	6.5	5.7	2.3	2.6	2.5	9.2	19.2	14.2
RWM	5.7	7.1	6.4	2.9	4.4	3.7	12.4	21.6	17.0
Mean	5.3	6.8	–	2.6	3.5	–	10.8	20.4	–
LSD ($p = 0.05$)									
Cropping system (CS)		0.6			0.8			2.1	
Residue (R)		0.5			0.7			1.7	
CS × R		0.8			1.0			2.5	

Note: RR = residue removed; RI = residue incorporated; RW = rice-wheat cropping system; RWM = rice-wheat-mungbean cropping system; LSD = least significant differences.

Table 8. Effect of residue incorporation on microbial biomass, dehydrogenase, and CO_2 evolution after completion of two cycles of rice-based cropping systems.

Cropping system	Microbial biomass			Dehydrogenase			CO_2 evolution		
	(μg g^{-1} soil)			(μg TPF g^{-1} soil 24 h^{-1})			(μg g^{-1} soil 24 h^{-1})		
	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean
RW	205.3	245.1	225.2	106.2	124.0	115.6	547.1	568.8	558.0
RWM	236.4	261.4	248.9	114.3	136.9	125.6	561.3	585.9	573.6
Mean	220.9	253.3		110.3	130.5	–	554.2	577.4	–
LSD ($p = 0.05$)									
Cropping system (CS)		25.4			9.5			9.6	
Residue (R)		13.8			15.3			7.8	
CS × R		NS			NS			NS	

Note: RR = residue removed; RI = residue incorporated; RW = rice-wheat cropping system; RWM = rice-wheat-mungbean cropping system; LSD = least significant differences; NS = non-significant.

evolution significantly. Interaction between cropping system and crop residue was not significant in respect of both biomass and CO_2 evolution in soil.

Physical properties of the soil

Since the bulk density, porosity, and hydraulic conductivity of the soil in 15 to 30 cm depth did not differ significantly after completion of two cycles of rice-based cropping systems, the data of soil in 0 to 15 cm depth are presented in Table 9. The effect of cropping systems and interaction effects of cropping systems and crop residue on physical properties of the soil in 0 to 15 depths were not significant after completion of two cycles of rice-based cropping systems. Bulk density in the surface soil progressively decreased in treated plots with crop residues, whereas porosity and hydraulic conductivity progressively increased significantly over plots without crop residues.

Discussion

Cropping systems

Currently there is a growing concern about the sustainability of RWCS (Duxbury et al. 2000; Ladha et al. 2000; Prasad and Nagarajan 2004; Prasad 2005), and there is an urgent need for alternative cropping systems. Duxbury et al. (2000) reported that 8 out of 11 long-term experiments on RWCS showed a decline in rice yield over time, whereas only 3 showed a decline in wheat yield. Similarly, Ladha et al. (2000), from a study of seven long-term experiments on RWCS, observed that none had a decline in wheat yield, while in two there was a decline in rice yield. Timsina et al. (1995) also confirmed yield decline in RWCS. Asian countries are facing an acute shortage of pulses (beans). During 2007–2008, 2.79 million Mg of pulses worth US$1.45 million were imported in India (FAI 2008). Based on an earlier experience (Sharma et al. 1995b; Sharma and Prasad 1999; Sharma et al. 2000), a summer mungbean crop was added to the two alternate cropping systems. Leguminous plants, either as pasture components or as green manure crops, are key parts of stockless organic rotations, as they help build and maintain soil fertility by fixing atmospheric N and adding organic matter to the soils. Hence, legumes are an important source of nutrients for most organic systems and crops under organic management.

Table 9. Effect of residue incorporation on physical properties of soil (0–15 cm) after completion of two cycles of rice-based cropping systems.

Cropping system	Bulk density			Porosity			Hydraulic conductivity		
	($Mg\ m^{-3}$ soil)			(%)			($cm\ h^{-1}$ soil)		
	RR	RI	Mean	RR	RI	Mean	RR	RI	Mean
RW	1.46	1.40	1.43	44.9	47.2	46.1	0.43	0.48	0.46
RWM	1.44	1.38	1.41	45.7	48.0	46.9	0.45	0.51	0.48
Mean	1.45	1.39	–	45.3	47.6	–	0.44	0.50	–
LSD ($p = 0.05$)									
Cropping system (CS)		NS			NS			NS	
Residue (R)		0.04			1.46			0.36	
CS × R		NS			NS			NS	

Note: RR = residue removed; RI = residue incorporated; RW = rice-wheat cropping system; RWM = rice-wheat-mungbean cropping system; LSD = least significant differences; NS = non-significant.

As expected, RWMCS was found to be more profitable than RWCS, as judged by rice equivalents, protein yield, and energy output. It was also found that the growing of summer mungbean and incorporating its residue increased rice yields in the second year of study. It is concluded that the benefits were mainly due to spring–summer mungbean. The advantage of growing a legume in a cropping system has been reported by several workers (Voss and Shrader 1979; Ebelhar et al. 1984; Kurtz et al. 1984; Rikerl et al. 1988; John et al. 1989). In addition to the N contribution by legumes, increased P, K, and micronutrient concentration and uptake by the succeeding crop has also been reported (Copeland and Crookstan 1992).

The only soil chemical property significantly affected by the different cropping systems was Kjeldahl N. RWMCS recorded significantly more Kjeldahl N in the soil than RWCS in the two years of study, due to the addition of *Rhizobium* to mungbean in RWMCS. As regards biological properties of soil, the population of bacteria, fungi, and actinomycetes was significantly more in RWMCS than in RWCS. Nair (1973), in a study with five different rice-based multiple cropping systems including rice-wheat, rice-potato-wheat, and rice-rapeseed-mungbean, observed that temperature had a dominating effect on the microbial population. In the present study, the possible reason for the higher microbial population in RWMCS over RWCS may be due to the fact that growing mungbean kept soil temperatures lower by providing soil cover; also, the crop received two irrigations. On the other hand, in the fallow plots, the hot summer sun, with a maximum temperature up to 45°C and a lack of moisture in the soil, reduced the microbial population. Temperature and moisture are the two main regulatory factors for microbial growth (Sharma et al. 1995), although the addition of biofertilizers (*Rhizobium*, PSB, and cellulotic culture) to mungbean in RWMCS also had a positive effect in this case. The higher microbial population in RWMCS resulted in higher microbial activity, which led to higher CO_2 evolution in the soil under RWMCS than under RWCS. The cropping systems had no significant effect on physical properties in 0–15 and 15–30 depths of soil after completion of two cycles of rice-based cropping systems.

Incorporation of crop residues

Rice and wheat crops produce a residue of 37.9 Tg y^{-1}, which is considered to be nearly one-fourth of the total crop residue produced in India (Sarkar et al. 1999). Each Mg of rice residue contains about 6.1 kg N, 0.8 kg P, and 11.4 kg K, while each Mg of wheat residue contains 4.8 kg N, 0.7 kg P, and 9.8 kg K (Sharma and Sharma 2002). Traditionally, rice and wheat residues are removed from the field and used as cattle feed and for several other purposes such as livestock bedding, thatching material for rural huts, and fuel. Recently, however, because of the advent of mechanized harvesting of rice and wheat, the farmers prefer to burn the residue *in situ*, especially that of rice due to a very short layover period of 2 to 3 weeks between rice harvest and wheat sowing. The burning of crop residues not only leads to loss of precious organic C and plant nutrients but also causes air pollution and is a health hazard. The effects of the incorporation of crop residues in RW differ from location to location (Prasad and Power 1991; Sharma 2001). While some researchers reported an increased yield of rice/wheat due to residue incorporation (Pandey et al. 1985; Alam and Azami 1989; Sharma and Mittra 1992; Sarkar 1997; Prasad et al. 1999), others failed to obtain such an advantage (Agarwal et al. 1995; Walia et al. 1995; Bijay-Singh et al. 2001). Some workers have even reported an adverse effect of incorporation of rice/wheat residue in the succeeding crop (Beri et al. 1995; Yadvinder et al. 1996). However, incorporation of cereal residues with legume residue results in an increased yield of the succeeding crop (Sharma and Prasad 2001).

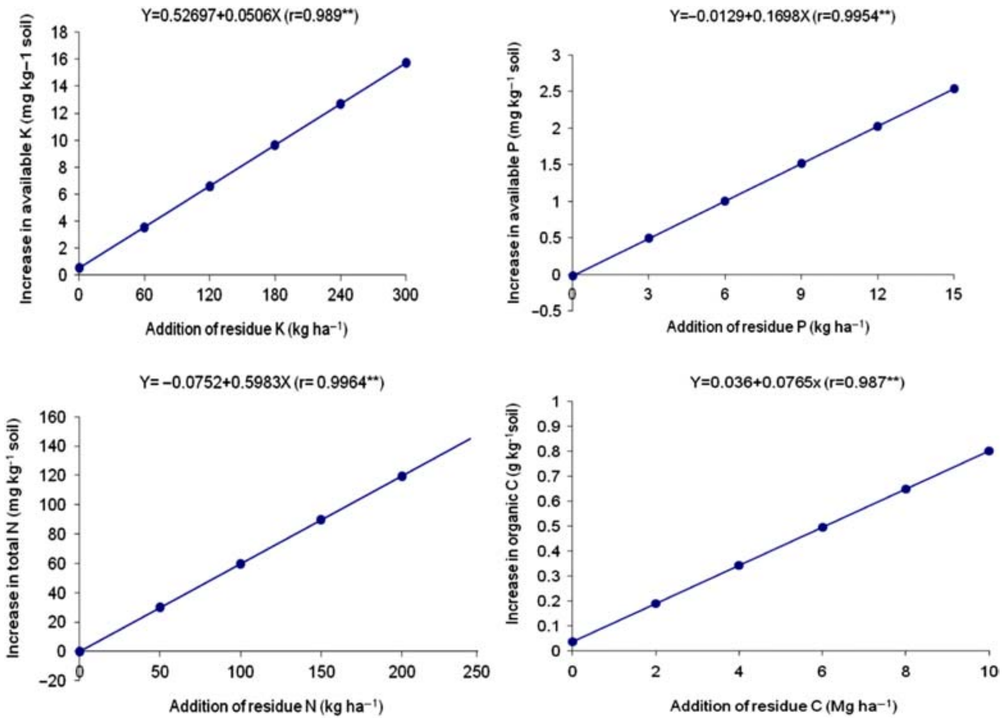


Figure 3. Relationship between addition of C, N, P, and K through crop residue and increase in organic C, total N, 0.5 M $NaHCO_3$ extractable P, and 1 N Nh_4OAC extractable K in soil.

In the present study, the rice yields were unaffected by the residue incorporation only in the first year of study. During the winter season, the wheat yield in both years of study was significantly increased due to residue incorporation. Most conspicuous was the significant increase in the yield of mungbean in the two years of study. It seems the crop residues encouraged the growth of *Rhizobia* in mungbean.

As could be expected, incorporation of crop residues increased Organic C, total Kjeldahl N, 0.5 M $NaHCO_3$ extractable P. and neutral 1N NH_4AOC extractable K in soil. A positive relationship was observed (Figure 3) between the addition of residue C, N, P, and K and organic C, total N, 0.5 M $NaHCO_3$ extractable P, and neutral 1 N NH_4OAC extractable K in 0–20 cm soil samples collected after the completion of each cycle of different cropping systems. An increase in organic C and total Kjeldahl N due to the incorporation of rice/wheat residues has been reported by several workers (Sharma et al. 1987; Beri et al. 1995; Prasad et al. 1999; Yadvinder et al. 2000; Sharma 2001). Beri et al. (1995) also reported an increase in available P and available K content in soil due to residue incorporation. A positive effect of organic residues on the microbial population is known. Also, the incorporation of residue helps in retaining soil moisture during the hot summer months when mungbean is grown. Such benefits of organic manures in cotton have been reported (Blaise and Prasad 2005). Sidhu et al. (1995) reported a significant increase in the bacterial and fungal population due to residue incorporation. In the present study, there also was an increase in bacterial, fungal, and actinomycetes populations, which resulted in a significant increase in microbial biomass and CO_2 evolution in soil with residue incorporation. The application of crop residue showed a significantly reduced bulk density and increased porosity and hydraulic conductivity after completion of two cycles. The combined use of organic manures (FYM) and crop residues improved the physical properties of the soil rather than a single organic manure application.

Sustainability issues

In general, soil health was better under RWMCS than under RWCS, making it more sustainable. One of the most important criteria of sustainable agriculture systems is that they should continue to meet human food needs (Brummer 1998; Prasad 2006). RWMCS achieves this to a greater extent than RWCS because of an increased production of edible protein, which is in short supply in India. Protein-energy malnutrition is rampant in India (Prasad 2003) and other developing countries. Thus, from the sustainability viewpoint, RWMCS is more sustainable than the present RWCS. The present study also indicates that rice-wheat-mungbean cropping systems hold considerable promise for organic farming. The proposed cropping system can also help in reducing the shortage of edible pulses in India. The incorporation of crop residues, in general, helps in maintaining soil health.

References

Agarwal RP, Phogat VK, Chand T, Grewal MS. 1995. Improvements of soil physical conditions in Haryana. In: Research highlights. Hisar (India): Department of Soils, C.C.S. Haryana Agricultural University. p. 69–75.

Alam SM, Azami AR. 1989. Influence of wild plant and crops residues on growth and nutrient content of wheat. Pak J Sci Indust Res. 32:749–751.

Beri V, Sidhu BS, Behl GS, Bhat AK. 1995. Nitrogen and phosphorus transformations as affected by crop management practices and their influence on crop yield. Soil Use Manage. 11:51–54.

Bijay-Singh B, Yadvinder-Singh KF, Khera TS, Pasuquin E. 2001. Nitrogen–15 balance and use efficiency as affected by rice residue management in a rice-wheat system in north-west India. Nutr Cycl Agroecosyst. 59:227–237.

Blaise D, Prasad R. 2005. Integrated plant nutrient supply—an approach to sustain cotton production. Indian J Fertil. 1(1):37–44.

Brummer CE. 1998. Diversity, stability and sustainable agriculture. Agron J. 90:1–2.

Cappuccino JG, Sherman N. 1999. Microbiology. A laboratory manual. 4th ed. Harlow (UK): Addison Wesley Longman.

Cochran WG, Cox GM. 1957. Experimental designs. New York (NY): Wiley.

Copeland PJ, Crookstan RK. 1992. Crop sequence effects on nutrient composition of corn and soybean grown under high fertility. Agron J. 84:503–509.

Duxbury JM, Abrol IB, Gupta RK, Bronson K. 2000. Analysis of long-term soil fertility experiments with rice-wheat rotation in South Asia. In: Abrol IP, Bronson K, Duxbury JM, Gupta RK, editors. Long-term soil fertility experiments in rice-wheat cropping system. Rice-Wheat Consortium Res. Ser. No. 6. New Delhi (India): Rice-Wheat Consortium for the Indo-Gangetic Plains. p. vii–xxii.

Ebelhar SA, Frye W, Blevins W. 1984. Nitrogen from legume cover crops for no-tillage corn. Agron J. 76:51–55.

FAI. 2008. 2007–2008. Fertilizer statistics. New Delhi (India): The Fertilizer Association of India.

Jasdan M, Hutchaon SS. 1996. Utilization of green manure for raising soil fertility in China. Soil Sci. 135:65–69.

Jenkinson DS, Ladd JN. 1981. Microbial biomass in soil: Measurement and turnover. In: Paul EE, Ladd JN, editors. Soil biochemistry. vol. 5. New York (NY): Marcel Dekker. p. 415–471.

John PS, Prasad R, Singh S, George M, Sharma SN. 1989. Effect of lentil residues on the yield and response of succeeding nitrogen. J Agron Crop Sci. 163:177–180.

Juliano BO. 1985. Polysaccharides, proteins and lipids of rice. In: Juliano BO, editor. Rice chemistry and technology. Los Banos (The Philippines): International Rice Research Institute (IRRI). p. 59–141.

Kopke MM. 1995. Studies on intercropping and biological N-fixation with *Azospirillum* in pearlmillet [master's thesis]. [New Delhi (India)]: IARI.

Kumar R, Yadav NSP. 2006. Improving the productivity and sustainability of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) system through mungbean (*Vigna radiata*) residue management. In: Proceedings of the National Symposium on Conservation Agriculture and Environment, 2006 January 6–8, BHU; Varanasi (Utra Pradesh State), India.

Kurtz LT, Boone IV, Peck TR, Hoeft RG. 1984. Crop rotation for efficient nitrogen use. In: Hanek RD, editor. Nitrogen in crop production. Madison (WI): American Society of Agronomy, Madison. p. 295–300.

Ladha JK, Fisher KS, Hossain M, Hobbs PR, Hardy B. 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic Plains: A synthesis of NARS–IRRI partnership research. Discussion paper no. 40. Los Banos (Philippines): IRRI. p. 1–31.

Lianzheng W, Yixian G. 1994. Rice-wheat systems and their development in China. In: Paroda RS, Woodhead T, Singh RB, editors. Sustainability of rice-wheat production systems in Asia. Bangkok (Thailand): ROAP, FAO. p. 160–171.

Nair PKR. 1973. Quantitative changes in soil microorganisms under rice based multiple cropping in northern India. Soil Biol Biochem. 5:387–388.

Ottow JCG, Glathe H. 1968. Rose bengal-malt extract agar, a simple medium for the simultaneous isolation and enumeration of fungi and actinomycetes from soil. Appl Microbiol. 16:170–171.

Pandey SP, Shankar H, Sharma VK. 1985. Efficiency of some organic and inorganic residues in relation to crop yield and soil characteristics. J Indian Soc Soil Sci. 33:178–181.

Piper CS. 1950. Soil and plant analysis. Adelaide (Australia): The University of Adelaide.

Prasad R. 2003. Protein-energy malnutrition and fertilizer use in India. Fertil News. 48(8):13–26.

Prasad R. 2005. Rice-wheat cropping system. Adv Agron. 86:285–339.

Prasad R. 2006. Towards sustainable agriculture in India. Natl Acad Sci Lett. 29:41–44.

Prasad R, Gangaiah B, Aipe KC. 1999. Effect of crop residue management in a rice-wheat cropping system on growth and yield of crops and on soil fertility. Exp Agric. 35:427–435.

Prasad R, Nagarajan S. 2004. Rice-wheat cropping system—food security and sustainability. Curr Sci. 87:1334–1335.

Prasad R, Power JF. 1991. Crop residue management. Adv Soil Sci. 15:205–251.

Prasad R, Shivay YS, Kumar D, Sharma SN. 2006. Learning by doing exercises in soil fertility. A practical manual of soil fertility. New Delhi (India): Division of Agronomy, Indian Agricultural Research Institute.

Rikerl DH, Gorden WB, Curl EA, Tonchton JT. 1988. Winter legume and tillage effects in cotton growth and soil ecology. Soil Till Res. 11:63–71.

Sarkar A. 1997. Energy-use pattern in sub-tropical rice-wheat cropping under short-term application of crop residue and fertilizer. Agric Ecosyst Environ. 61:55–67.

Sarkar A, Yadav RI, Gangwar B, Bhatia PC. 1999. Crop residues in India. Modiputram (India): Project Directorate for Cropping Systems Research.

Sharma AR, Mittra BN. 1992. Integrated nitrogen management in rice (*Oryza sativa*)—wheat (*Triticum aestivum*) cropping system. Indian J Agric Sci. 62:70–72.

Sharma GD, Mishra RR, Ksattriya S. 1995a. Fungi and litter decomposition in the tropics. In: Reddy MV, editor. Soil organisms. New Delhi (India): Oxford and IBH. p. 39–57.

Sharma HL, Singh CM, Modgal SC. 1987. Use of organics in rice-wheat crop sequence. Indian J Agric Sci. 57:163–168.

Sharma SK, Sharma SN. 2002. Integrated nutrient management for sustainability of rice-wheat cropping system. Indian J Agric Sci. 72:573–576.

Sharma SN. 2001. Effect of residue management practices and nitrogen rates on chemical properties of soil. Indian J Agric Sci. 71:293–295.

Sharma SN, Prasad R. 1999. Effect of *Sesbania* green manuring and mungbean residue incorporation on productivity and nitrogen uptake of a rice-wheat cropping. Bioresour Technol. 67:171–175.

Sharma SN, Prasad R. 2001. Effect of wheat, legume and legume-enriched wheat residues on the productivity and nitrogen uptake of rice-wheat cropping system and soil fertility. Acta Agron Hungarica. 49:369–378.

Sharma SN, Prasad R, Singh S. 1995b. The role of mungbean residues and *Sesbania aculeata* green manure in the nitrogen economy of rice-wheat cropping system. Plant Soil. 172:123–129.

Sharma SN, Prasad R, Singh S, Singh P. 2000. On-farm trials of the effect of introducing a summer green manure of mungbean on the productivity of rice-wheat cropping system. J Agric Sci Cambridge. 134:169–172.

Sharma SN, Sharma SK. 2004. Role of crop diversification and integrated nutrient management in resilience of soil fertility under rice-wheat cropping system. Arch Agron Soil Sci. 50:511–519.

Sidhu BS, Beri V, Gosal SR. 1995. Soil microbial health as affected by crop residue management. In: Benbi DK, Brar MS, Bansal SK, editors. Proceedings of the National Symposium on Developments in Soil Science; 1995 Nov 2–5; Ludhiana (India). New Delhi (India): Indian Society of Soil Science. p. 45–46.

Singh ID, Paroda NC. 1994. Harvest index in cereals. Agron J. 63:224–226.

Singh S, Pannu CJS, Singh S, Singh IP, Kaur S. 1996. Energy in Punjab agriculture. Technical Bulletin. Ludhiana (India): Department of Farm Power and Machinery, Punjab Agriculture University.

Subba Rao NS. 1977. Soil microorganisms and plant growth. New Delhi (India): Oxford and IBH.

Timsina I, Singh U, Singh Y, Lansigan EF. 1995. Addressing sustainability of rice-wheat system: Testing and application of CERES and SUCROS models. In: Zeigher RS, editor. Fragile lives in fragile ecosystems. Manila (Philippines): IRRI. p. 633–656.

Veihmeyer FJ, Hendrickson AH. 1948. Soil density and root penetration. Soil Sci. 65:487–493.

Voss RD, Shrader WD. 1979. Rotation effects and legume sources of nitrogen for corn. In: Bezdicek DA, Power JF, editors. Organic farming. Current technology and its role in sustainable agriculture. ASA Special Publication 46. Madison (WI): American Society of Agronomy. p. 61–68.

Walia SS, Brar SS, Kler DS. 1995. Effect of management of crop residues on soil properties in rice-wheat cropping systems. Appl Soil Ecol. 16:63–76.

Yadvinder S, Bijay S, Maskina MS, Meelu OP. 1996. Organic manuring and crop residue recycling for sustained soil and crop productivity in rice-wheat cropping system. In: Pathak PS, Gopal B, editors. Studies in Indian agroecosystem. New Delhi (India): National Institute of Ecology. p. 73–83.

Yadvinder S, Bijay S, Meelu OP, Khind CS. 2000. Long-term effects of organic manuring and crop residues on the productivity of rice-wheat cropping system in north-west India. In: Abrol IP, Bronson K, Duxbury JM, Gupta RK, editors. Long-term soil fertility experiments in rice-wheat cropping system. New Delhi (India): Rice-Wheat Consortium for the Indo-Gangetic Plain. p. 14–162.