8. Total Factor Productivity of Rice-Wheat Cropping Systems in India - The Role of Legumes

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Abstract

During the past three decades, the rice-wheat cropping systems (RWCS) in India significantly contributed to enhancing food grain production and achieving food self-sufficiency and food security. The production system now is under threat due to stagnating or declining total factor productivity. Legumes can play a significant role in enhancing the factor productivity of this most important and productive production system in the country. Ironically, rice and wheat have replaced the principal legumes over a period of time. With the availability of high-yielding and short-duration varieties of important legumes, there is a need to incorporate them in RWCS to improve the sustainability of the system so as to meet future food grain demands without degradation of the natural resource base.

Introduction

Rice (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping systems (RWCS) gained prominence from the mid-1960s with the introduction of short-duration and high-yielding varieties of rice and wheat. The rotation has spread in the most fertile regions and has covered about 10 million ha in the Indo-Gangetic Plain (IGP) of India. It is more popular in the non-traditional rice-growing states of Punjab, Haryana, and Uttar Pradesh, and less in traditional rice-growing states of Bihar and West Bengal. The impressive performance of the system during the past three decades resulted in a quantum jump in the production of rice and wheat, which largely contributed in achieving the food self-sufficiency in India. The food grain production in India increased from about 90 million t in 1964-65 to about 190 million t in 1994-95 at an annual growth rate of >2.5%.

While the rapid growth in rice and wheat production yielded high dividends, it was realized during the late 1980s that gains might not be sustainable. Currently, there is a growing concern about the sustainability of RWCS, as the growth rates of rice and wheat yields are either stagnating or declining (Paroda et al. 1994). The productivity of rice and wheat in some parts of India has already ceased to increase and in a few states it has shown declining trends. Chaudhary and Harrington (1993) have shown that the expansion in rice and wheat area in Haryana has halted, growth in rice productivity has slowed down, and historical sources of productivity growth have exhausted much of their potential. Cultivation of rice and wheat has become less profitable over time. The threat is further aggravated when it is realized that the country needs to meet the growing food grain requirement of about 220.5 million t by 2001-2 and 243.2 million t by 2006-7 (Kumar and Mathur 1996). It is expected that about 80% of the total food grain demand will be for rice and wheat (Kumar 1997). The annual shortfall in the supply of rice and wheat by 2020 was projected to be about 32 million t.

The main questions now being raised by scientists and policy makers in this regard are:

- To what extent is the sustainability of the RWCS threatened?
- How can legumes and organic manures sustain the productivity of the system?
- How can any damage that has so far occurred be alleviated?

This chapter examines these issues to better characterize the performance of the RWCS. More specifically, the objectives of the

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chapter are to:

- Assess the significance of the RWCS in improving the food security of India.
- Diagnose changing use of traditional and modern inputs in the RWCS.
- Analyze the indicators of sustainabilily in RWCS.
- Examine the role of legumes in improving the sustainability of RWCS.

Methodology

Study Area

The study is confined to the 1GP of India. The entire region can be divided into two major cropping systems: (1) RWCS, and (2) Rice-based cropping systems. The former is largely confined to Punjab, Haryana, and Uttar Pradesh, and to some extent in Bihar and West Bengal, where rice and wheat are grown in a sequence. The second system is practiced more in large parts of Bihar and West Bengal, and to some extent in eastern Uttar Pradesh, where land is either kept fallow or cultivated to rice in the postrainy season.

Data

Data on area, production, yield, irrigated area, adoption of high-yielding varieties, farm harvest prices of rice, wheat, and important legumes were collected from published sources from 1970 to 1995 (Government of India 1995). This dataset was complemented by the farm-level data on yield, and use of inputs and their prices, which were collected from the 'Comprehensive Scheme for the Study on Cost of Cultivation of Principal Crops', Directorate of Economics and Statistics, Government of India.

Quantification of Sustainability

Total (actor productivity (TFP) is one measure of quantifying sustainability of any system. Lynam and Herdt (1988) argued that the appropriate measure of output, which determines sustainability of the crop, cropping system, or farming system is the TFP. It is defined as the total value of all output produced by the system over one cycle divided by the total inputs used by the system over one cycle of the system. It measures the amount of increase in total output, which is not accounted for, by the increase in total inputs. A sustainable system would have a non-negative trend in TFP over the period of concern. Later, Ehui and Spencer (1990) used inter-temporal factor productivity to measure the sustainability of a crop or farming system. During the past two decades or so, several studies on TFP have been published for India (Evenson and Jha 1973; Rosegrant and Evenson 1992; Sidhu and Byerlee 1992; Kumar and Mruthyunjaya 1992; Kumar and Rosegrant 1994; and Jha and Kumar 1996).

This paper used the Divisia-Tornqvist index (Diewert 1976) to measure TFP as an indicator of sustainability. The total output, input, TFP, and input price indices were computed as follows:

Total output index (TOI):

$$TOI_t / TOI_{t-1} = (Q_{it} / Q_{it-1})\,(R_{it} + R_{it-1})^{1/2}$$

Total input index (TII):

$$TII_t / TII_{t-1} = (X_{it} / X_{it-1})\,(S_{it} + S_{it-1})^{1/2}$$

TFP:

$$TFP_t = (TOI_t / TII_t)$$

Input price index (IPI):

$$IPI_t / IPI_{t-1} = (P_{it} / P_{it-1})\,(S_{it} + S_{it-1})^{1/2}$$

where, 'R_{lt}' is the share of output, 'j' is total revenue, 'Q ' is the output 'j', 'S_{it}' is the share of input 'I' in total input cost, 'X_{it}' is input 'I', 'P_{it}' is the price of input 'I', and 't' is the time variable. By specifying $TOI_{t\,1,}$ TII, and IPI are equal to 100 in the base year (1981-82), the above equations provide the indices of total output, total input, TFP, and input prices for the specified period 't'. The real cost of production of different crops was computed by deflating the cost of production by the IPI.

Significance of the RWCS

Extent of the RWCS

Precise information on extent of RWCS is not available. Some estimates are being made, which reveal that RWCS area was spread over 10 million ha in the IGP of India in 1993 (Table 8.1). During the past three decades, the area under this system has risen by more than 6 million ha. About 75% of the total rice area and 63% of wheat area in the IGP was under the RWCS in 1993. The state level disaggregation showed that entire rice area in Punjab and Haryana, and about 96% in Uttar Pradesh was under the RWCS. In Bihar, the corresponding figure was 40%. Negligible rice area in West Bengal was under this cropping system. On the other hand, almost all the wheat area (which is too low when compared with rice area) in Bihar and West Bengal was in rotation with rice. The corresponding wheat area in the RWCS in Punjab and Uttar Pradesh was >60%. It was 36% in Haryana. This suggests that about 40% of the wheat area in Punjab and Uttar Pradesh, and about 64% in Haryana was rotated with crops other than rice.

Table 8.1. Estimated area under rice-wheat cropping systems in the Indo-Gangetic Plain (IGP) of India[1].

	Area of rice-wheat system (million ha)		Area under rice-wheat rotation as percentage of total rice area		Area unde rice-wheat rotation as percentage of total wheat area	
State	1983	1993	1983	1993	1983	1993
Punjab	1.4	2.0	100	100	44	63
Haryana	0.5	0.7	100	100	30	36
Uttar Pradesh	5.1	5.3	94	96	61	61
Bihar	1.7	1.9	37	40	96	96
West Bengal	0.1	0.3	2	4	41	98
IGP	8.8	10.0	72	75	58	63
All India	11.5	12.3	29	30	49	52

1. Average of triennium ending 1983 and 1993
Source: Government of India (1995).

Cereal Production and RWCS

The RWCS has substantially contributed to the food grain basket of the country, which made India a self-sufficient nation. During 1993, the RWCS contributed more than 50% of the cereal production in the IGP (Table 8.2). About 75% of Punjab's cereal production was from the RWCS. More than 50% of the cereal production in Uttar Pradesh and Bihar was contributed by the RWCS. In Haryana, 45.7% of the cereal production was contributed by the RWCS. In West Bengal, it was less than 10%. At aggregate level, the RWCS contributed >50% to total cereals production in the IGP. Thus sustainability of the RWCS in the IGP is of great significance to meet the country's growing demand for food grain.

Rice and Wheat Procurement

The significance of the RWCS can be seen by the procurement of rice and wheat from the region (Table 8.3). The available information

Table 8.2. Contribution of rice-wheat cropping systems (RWCS) in total cereal production in the Indo-Gangetic Plain (IGP) of India.

	Production from RWCS (million t)		Total cereal production (million t)		Contribution of RWCS in total cereal production (%)	
State	1983	1993	1983	1993	1983	1993
Punjab	8.2	14.1	13.9	19.7	59.0	74.6
Haryana	2.6	4.3	6.2	9.4	41.9	45.7
Uttar Pradesh	14.8	20.4	24.0	33.2	61.7	61.7
Bihar	3.9	5.5	7.7	8.9	58.6	61.8
West Bengal	0.9	1.1	6.9	12.4	13.0	8.9
IGP	29.9	44.7	58.7	83.6	50.9	53.5
All India	35.6	50.4	125.6	160.7	28.3	31.4

Source: Government of India (1995).

showed that about 76% of the total food grains in the country were procured from the IGP in 1994-95. About 95% of wheat and 60% of rice procurement came from the IGP. Punjab alone contributed about 60% of wheat and 42% of rice in total food grain procurement in the country. These evidences confirm that the RWCS is the backbone of the public distribution system and food security of the poor. Any threat to this system may seriously affect the food security of the poor living within and outside of IGP.

Table 8.3. Procurement of food grains (million t) in 1994-95 by government agencies from the Indo-Gangetic Plain (IGP) of India.

State	Rice	Wheat
Punjab	5.8	7.3
Haryana	1.4	3.1
Uttar Pradesh	0.7	1.3
Bihar	Negligible	0
West Bengal	0.2	0
IGP	8.2	11.7
All India	13.7	12.3
Share of IGP in all India (%)	6.0	9.5

Declining Growth in Production

Currently, the issue of concern is the stagnating yields of rice and wheat in the most productive regions of the IGP. To verify the emerging concern, state-wise growth rates in production, area, and yield of rice and wheat were computed for 1972-85, 1985-95, and 1972-95 periods (Table 8.4). Although yields of rice and wheat showed increasing trends, the rates of growth in production during 1985-95 were lower in comparison with those during 1972-85 in Haryana and Punjab. Annual compound growth rate of rice yield in Punjab was 4% during 1972-85, while it declined to 0.9% in 1985-95. The corresponding changes in growth rates of rice yields in Haryana were 3.7% and 0.8%. The area expansion was the major source of production growth in these states. In other states, the yields were yet to reach the potential level, and there was still enough scope to increase yields of rice. In case of wheat, the yield growth rates were positive and increased from 2.8% in 1972-85 to 4.2% in 1985-95 in the IGR Yield increase was still a main source of increasing wheat production in all the states. Slower rate of growth in production of rice and wheat during 1985-95 as compared to 1972-85 in Punjab and Haryana is a matter of serious concern as these states contribute major share of total food grain procurement for rest of the country.

Input Use Pattern

Changes in the Input Use

Date on cost of cultivation for the years 1976, 1985, and 1992 were used to examine the changes in traditional and modern inputs in the

Table 8.4. Annual compound growth rates (%) of area, production, and yield of rice and wheat in the Indo-Gangetic Plain (IGP) of India.

		Rice			Wheat		
State	Parameter	1972-85	1985-95	1972-95	1972-85	1985-95	1972-95
Punjab	Production	14.8	4.0	9.7	5.1	2.9	4.5
	Yield	4.0	0.9	2.3	2.6	2.3	2.5
	Area	10.8	3.1	7.4	2.5	0.6	1.5
Haryana	Production	9.8	4.3	6.4	6.1	4.7	5.8
	Yield	3.7	0.8	1.9	2.7	3.2	3.0
	Area	6.1	3.5	4.5	3.4	1.5	2.8
Uttar Pradesh	Production	4.6	3.7	4.2	6.7	7.1	6.9
	Yield	3.1	3.3	3.2	3.7	6.4	5.0
	Area	1.5	0.4	1.0	3.0	0.7	1.9
Bihar	Production	-1.0[1]	-0.3[1]	1.1	1.7	3.6	3.1
	Yield	-0.8[1]	-0.9[1]	1.5	0.5	2.8	1.9
	Area	-0.2[1]	-1.2	-0.3	1.2	0.8	1.2
West Bengal	Production	0.5	4.6	3.2	-2.1	-1.2[1]	-1.8
	Yield	0.5	3.3	2.6	0.0	-0.8[1]	0.0
	Area	0.0	1.3	0.6	-2.1	-2.0	-1.8
IGP	Production	3.2	3.4	3.3	5.4	4.9	5.2
	Yield	2.2	2.8	2.5	2.8	4.2	3.8
	Area	1.0	0.6	0.8	2.6	0.8	1.4

1. Not significant

RWCS (Tables 8.5 and 8.6). Two important features were observed: (1) use of inorganic fertilizers has remarkably increased, while that of organic sources of nutrients, namely farmyard manure and legumes, have declined; and (2) irrigation and improved varieties have almost reached the ceiling levels. Almost 90% area was sown under high-yielding varieties, about 80% area was under irrigation, and 260 kg ha^{-1} of chemical nutrients were used in rice and wheat. Fertilizer

Table 8.5. Annual compound growth rates (%) of inputs and yield in the rice-wheat cropping systems in the Indo-Gangetic Plain (IGP) of India during 1976-92.

Input/Yield	Punjab	Haryana	Uttar Pradesh	IGP
Traditional inputs				
Seed	0.7	0.4	-1.7	-1.4
Manure	0.3	-10.4	-10.2	-5.6
Modern inputs				
Fertilizers	3.9	3.9	5.3	5.5
Pesticides	14.8	22.9	11.0	17.2
Labor and machine				
Human labor	-2.6	-1.0	-1.5	-1.8
Bullocks	-12.9	-9.1	-5.5	-6.9
Machines	3.8	2.8	7.0	6.3
Rice-wheat				
Yield	2.5	1.7	2.1	2.4

Table 8.6. Estimated factor shares (%) in total cost of production of rice and wheat in the Indo-Gangetic Plain (IGP) of India[1].

	Punjab		Haryana		Uttar Pradesh		IGP	
Factor	I	II	I	II	I	II	I	II
Land	26	38	24	26	26	23	26	28
Seed	4	3	4	3	6	6	5	5
Labor	24	17	22	22	22	22	22	21
Bullocks	8	1	14	3	17	10	15	6
Machines	5	12	5	10	4	11	4	11
Fertilizer	15	12	11	12	9	8	10	10
Manure	1	<0.5	1	<0.5	3	<0.5	2	<0.5
Pesticide	<0.5	3	<0.5	3	<0.5	<0.5	<0.5	1
Irrigation	10	6	11	11	5	6	6	7
Interest due	7	8	8	10	8	13	8	11

1. I = 1974-76; II = 1990-92.

consumption in rice and wheat crops in Punjab was about 400 kg ha^{-1} in 1992, while in Uttar Pradesh it was <200 kg ha^{-1}. Sidhu and Byerlee (1992) reported that in some of the major developed districts of Punjab, such as Ludhiana, fertilizer has already exceeded the recommended dose. Hence, growth in the use of fertilizer and fertilizer's marginal contribution to yield are expected to be substantially lower in the future than what were realized in the past.

Adoption of high-yielding varieties and irrigation coverage have almost reached the ceiling level although scope still exists to adopt several new high-yielding varieties and efficient methods of using water and other critical inputs to attain higher growth in yield. In contrast to the use of high-yielding varieties and irrigation, which had reached a high level in almost all major RWCS areas during the early period, use of fertilizer [NPK (nitrogen, phosphorus, potassium)] continued to increase rapidly from about 107 kg NPK ha^{-1} in 1976 to 259 kg NPK ha^{-1} in 1992—an annual growth rate of 5.5%. By 1992, average fertilizer use had reached over 85% of the recommended dosage in Punjab, 60% in Haryana, and about 50% in Uttar Pradesh. In the 1980s, the use of pesticides/herbicides was too low, which increased manifold in Punjab and Haryana in early 1990s as compared to 1980s.

In contrast to the use of inorganic fertilizers, there was strong evidence that use of organic manure has declined substantially in the IGP. At aggregate level, it declined by about 5% annually during 1976-92 period, and its consumption decreased to <2 t ha^{-1} in 1992 from about 5 t ha^{-1} in 1976. This decline might have occurred because the cropped area has expanded much faster than the livestock numbers as bullocks have been replaced by tractors.

The use of labor-saving technologies, especially the tractors, has expanded rapidly and substituted for human and bullock labor (Table 8.6). The most prominent change has occurred in the use of animals; the annual growth rate has declined by 13% in Punjab, followed by 9% in Haryana, and 6% in Uttar Pradesh. The annual growth rate of human labor use has also decreased by 1-3%. The share of bullocks in the total cost of rice and wheat production fell sharply, while that of machines (largely tractors, harvesters, and combine) increased rapidly. The share of modern inputs in total cost has increased substantially over the past two decades in the IGP.

Real Cost of Production

As expected, with rapid technical change, the unit cost of production (at constant prices) of rice and wheat decreased steadily at an annual rate of 3.2% in Punjab, 2.6% in Haryana, and 2.4% in Uttar Pradesh during 1976-92 (Table 8.7). The unit cost of production of rice and wheat continued to decline during the 1985-92 period. However, the rate slowed down to -1.8%) in Punjab and -1.7% in Haryana, while it stagnated in Uttar Pradesh. The decline in the unit cost of production due to technological change and input subsidies has resulted in substantial increase in the marketable surplus of wheat and rice. These contributed to food security mainly by inducing sharp decline in real prices of rice and wheat grains (Table 8.8). Many of the benefits of higher efficiency in the use of inputs and lower unit costs of

Table 8.7. Trends in indices of unit cost of rice and wheat production at constant prices in the Indo-Gangetic Plain (IGP) of India.

	Index (%)			Annual growth rate (%)		
State	1976	1985	1992	1976-85	1985-92	1976-92
Punjab	185	131	114	-4.3	-1.8	-3.2
Haryana	173	131	116	-3.4	-1.7	-2.6
Uttar Pradesh	160	120	118	-2.7	0.0	-2.4
IGP	168	123	114	-3.3	-1.0	-2.9

Table 8.8. Trends in indices of per unit prices of rice and wheat at constant prices in the Indo-Gangetic Plain (IGP) of India.

State	Index (%)			Annual growth rate (%)		
	1976	1985	1992	1976-85	1985-92	1976-92
Punjab	109	96	99	-1.5	0.2[1]	-1.2
Haryana	123	104	133	-2.0	3.1	0.2[1]
Uttar Pradesh	105	94	102	-1.2	0.9	-0.7
IGP	106	93	104	-1.3	0.9	-0.7

1. Not significant.

production that technological change has generated were shared by both fanners and consumers. The farmers gain because of higher crop yields and production, while the consumers benefited by higher purchasing power due to lower prices. The fall in prices of grains have benefited the urban and rural poor more than the upper income groups, because the former spend a much larger proportion of their income on these crops than the latter (Kumar 1997).

Table 8.9. Trends in indices of total factor productivity (TFP) in rice-wheat cropping systems in the Indo-Gangetic Plain (IGP) of India.

State/Index	Index[1] (%)			Annual growth rate (%)		
	1976	1985	1992	1976-85	1985-92	1976-92
Punjab						
Input	47	137	172	10.9	3.3	7.2
Output	36	135	178	14.0	4.1	9.1
TFP	76	98	103	3.2	0.8	1.9
Harvana						
Input	63	114	156	5.3	5.2	4.2
Output	53	118	162	7.7	5.1	5.6
TFP	84	104	104	2.4	-0.1[2]	1.4
Uttar Pradesh						
Input	89	94	I N	0.9	3.5	1.4
Output	88	121	137	3.1	2.3	2.9
TFP	99	128	120	2.2	-1.2	1.6
IGP						
Input	78	105	128	3.2	3.5	3.4
Output	70	126	152	6.1	3.1	4.9
TFP	89	120	119	2.9	-0.4[2]	1.5

1. Average figures for triennium ending 1976, 1985, and 1992; the base year is 1980.
2. Not significant.

Total Factor Productivity (TFP)

Measurement of TFP

The average annual growth rates of outputs, inputs, and TFP indices for the RWCS in the Indian states of IGP are given in Table 8.9. The results revealed that in Punjab, the input index during 1976-92, has risen at the rate of 7.2%, whereas it was 4.2% in Haryana and 1.4% in Uttar Pradesh. With the input and technological change, the output increased by 9.1% in Punjab, 5.6% in Haryana, and 2.9% in Uttar Pradesh. Thus the TFP growth rate (during 1976-92 period) in the RWCS was estimated at 1.9% in Punjab, 1.4% in Haryana, and 1.6% in Uttar Pradesh. Overall in the IGP, the annual increase was 3.4% for input index, 4.9% for output index, and 1.5% for TFP index. The growth in the TFP was responsible for about 21% increase in output growth of rice and wheat in Punjab, 25% in Haryana, and 55% in Uttar Pradesh. The highest growth in rice-wheat production during 1976-92 was attributed to higher use of inputs in Punjab followed by Haryana and Uttar Pradesh. This suggests that the future output growth will largely be achieved by using more inputs. However, in these states use of modern inputs had already reached high levels in the early period.

During the period 1976-85, the growth in output was almost equally contributed by the growth in use of inputs and TFP. Later (1985-92), the growth rate in TFP for the RWCS declined (-1.2%) in Uttar Pradesh, near stagnated (0.8%) in Punjab, and totally stagnated (-0.1%) in Haryana. Such a phenomenon has two important implications: (1) the qualitative change due to improved technology has disappeared in the IGP; and (2) positive growth in output has been achieved as a result of input quantities. Negative and stagnating growth in the TFP is a matter of concern in the IGP.

Role of Legumes

Earlier studies (Kumar and Mruthyunjaya 1992; Rosegrant and Evenson 1992; Kumar and Rosegrant 1994) showed that research, extension, infrastructure, and literacy were the important sources of growth in TFP. Historically, legumes are known to improve soil fertility. Their importance has more significance in the RWCS where organic sources of soil fertility improvement have rapidly declined. Ladha et al. (1996) documented potential benefits of legumes in sustaining soil fertility. Joshi (1998) documented evidence that legumes contributed in saving nitrogenous fertilizers and improving soil fertility.

To confirm the role of legumes in the sustainability of the RWCS, legumes area is included as one of the variables in the TFP decomposition model along with a trend variable. Inclusion of trend variable was to capture the aggregate effect of research stock, expenditure on extension, infrastructure, and literacy on TFP. The estimated TFP decomposition equation for the RWCS in IGP is given below:

$$\underset{}{\text{Ln TFP}} = \underset{}{3.7125} + \underset{(3.98)}{0.1382}\text{" Ln ARLEG} + \underset{(5.68)}{0.0445}\text{" T} - \underset{(2.81)}{0.0011}\text{" TT}$$

Adjusted R^2 = 0.60

where Ln = natural logarithm; TFP = index of TFP in RWCS; ARLEG = index of legume area; T = trend variable (starting from 1973); TT = square term of trend variable. Figures in parentheses are the student t-statistics, and ** is significance at 1% probability level.

The effect of legume area on TFP of RWCS is positive and highly significant which suggests that the role of legumes is of crucial importance for the growth in productivity and for sustaining the RWCS in IGP. Legumes productivity may be encouraged to improve the sustainability of rice and wheat crops in IGP.

Summary and Conclusion

The RWCS is spread in the most fertile regions covered by the IGP. In India, the system is prominent in the states of Haryana, Punjab, and Uttar Pradesh, where three-quarters of the total rice area and more than half of the wheat area is under the RWCS. The production system contributes about one-third of India's total cereal production. As high as 95% of the wheat procurement, and 60% of rice procurement comes from the RWCS of the IGP. The sustainability of the RWCS in IGP is critical for the country's public distribution system and food security.

The share of TFP in the growth rate of rice and wheat production is declining. The yield growth is more input based. The use of modern inputs (e.g., high-yielding varieties, irrigation, chemical fertilizers, and pesticides) in the IGP has already been achieved to a high level. The organic sources of nutrients (such as organic manure and legumes area) are rapidly declining in the RWCS. Further scope of increasing yield of rice and wheat from modern inputs and area expansion seems to be remote. Better management of existing soil and water resources

can enhance the growth in yield and production of the RWCS.

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