Is the Green Revolution Vanishing? Empirical Evidence from TFP Analysis for Rice

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1. Introduction

The introduction of first modern varieties (MVs) *Kalyansona* of wheat in 1967 and *Jaya* of rice in 1968 kicked off the beginning of Green Revolution (GR) in India. Since then, about 2500 MVs of different food, fodder, fiber, and horticulture crops were released-primarily from the public sector R&D system-over the past 35 years of GR period. The favorable public policy support in the form of price and market support, input subsidy, infrastructure especially irrigation development, etc., besides the access of the suitable MVs in the 60s and 70s induced the farmers to invest more land, labor and capital resources for the extensive and intensive cultivation of rice and wheat-particularly in the irrigated environments. The phenomenal increases in yield of rice and wheat crops were the chief sources of increased food grain production over the past 35 years of GR period in India.

Rice is a principal food crop, which occupies nearly one-fourths of the gross irrigated area in India. Majority of agricultural and food policy initiatives over the period were largely centered on rice and also wheat. Public sector R&D has given a top priority for the rice improvement in terms of resource allocation-both capital and human resources. The crop breeders have released nearly 650 MVs of rice over the past 35 years in India. The MVs released till mid 70s were largely higher yielders while subsequent generations of MVs were mainly either with improved resistance to pests and diseases or with grain quality (Janaiah, 2004). These improvements in the successive generations of MVs are expected to reflect in the productivity growth in three ways viz., lowering the cost of production, higher market price per unit output, and lowering yield instability. However, a serious concern has been raised on the long run sustainability of the productivity effects of GR technologies under irrigated ecosystem due to degradation of natural resource-base. Many recent studies reported that rice yields were either declining or stagnant after the 1980s under the intensive irrigated rice systems due to various resource-degradation problems (Flinn and De Datta 1984; Cassman and Pingali, 1995, Nambiar, 1995, Pingali et al. 1997, Greenlands, 1997; Yadav, et al., 2000, Dawe et el. 2000; Kumar and Yadav, 2001). Most of these studies were however largely based on experimental data designed with a specific objective under controlled environments (fixed nutrient doses, variety, other management practices, etc.) in the research farms and adaptive research trials. These studies provide an impression that productivity impact of technological progress has been vanishing in the irrigated systems. But, the yield trends of MVs from the 'controlled environment' may not be matched with those of the farmers' fields (real farm environment)-because farmers access and adopt new MVs, and adjust their farm practices over the period to cope up with the changing production and micro policy environments.

It is also essential to recognize a fact the yield growth is not a true measure of technology impact, as it does not net out the effect of input growth from output growth. Thus, total factor productivity (TFP) growth is a correct measure of productivity impact of technical change (Even son and Pray, 1991). The principal goal of the paper is to provide an empirical evidence on core issue of whether the productivity impact of the technological progress is vanishing through GR period. Specific objectives of the paper are (i) to examine the trends in rice yields by ecosystem and state, and (ii) to analyze the total factor productivity (TFP) for rice by state.

The paper is organized as follows. The data sources and methods of analysis were explained in the next section. Section-3 discusses the results on long-term growth trends of yield by ecosystem and state, and TFP across the Indian states. The last section concludes with summary.

2. Data Sources and Methods of Analysis

Data source

Time-series data on rice yields for major rice-ecosystems were obtained from the databank of the International Rice Research Institute (IRRI), which were compiled from various sources of Ministry of Agriculture, Government of India. State level statistics on area, production and yields, area irrigated, and area planted to modern varieties was compiled for the period 1970 to 2003 from the respective state's Bureau of Economics and Statistics. Input-output data from the reports of a comprehensive scheme *Cost of Cultivation of Principal Crops in India*, Ministry of Agriculture, Government of India were compiled, and used for measurement and analysis of TFP growth.

Estimation of TFP growth

In common parlance, productivity growth in agriculture crops is assessed through a change in crop yields measured as production per unit of land between two points of period. It has a clear physical connotation and allows for cross-section and time series comparisons. They are, however, incomplete as measures of economic efficiency, because they do not explicitly consider the growth in use of inputs other than land such as labour, fertilizer, animal power, etc. Changes in the use of these inputs over a period of time also bring a considerable change in yields, but at a cost (Evenson, *et al.*, 1999). Consequently, changes in physical yield are not true measures of productivity from efficiency perspective. Total factor productivity (TFP), some times referred to as multifactor productivity, is a true measure of economic efficiency. It can be interpreted as a measure of change in cost of producing a unit of product, holding all factor prices constant (Evenson and Pray 1991). Alternatively TFP growth provides changes in output growth that is not due to input growth. Thus, TFP is considered as an indicator of technological progress over the period.

There are number of studies in recent years on measurement and analysis of TFP for various crops and/or group of crops in Indian agriculture (Sidhu and Byrlee, 1992; Rosegrant and Evenson, 1992 and 1993; Kumar and Mrithyunjaya, 1992; Dholakia and Dholakia, 1993; Kumar and Rosegrant, 1994; Fan, 1998; Evension et al, 1999; Pingali and Heisy, 1999). Most of these studies used either Divisia index or alternatively Tornqvist-Theil index of conventional TFP measures. These studies reported that TFP growth for various crops and/or agriculture in India was about 0.6 to 1.3 per cent per year during 1966-1995, with a deceleration in TFP growth after the mid 1980s.

For this paper, Tourvist-Theil index method applied for TFP estimation because of not only its methodological superiority over conventional Divisia index (Rosegrant and Evension, 1992), but also its simplicity in estimation-especially for single crop. The TFP index method is explained below.

$$TFP \approx In\left(\frac{TFP_t}{TFP_{t-1}}\right) = In\left(\frac{QI_t}{QI_{t-1}}\right) - In\left(\frac{XI_t}{XI_{t-1}}\right)$$

$$= \sum In\left(\frac{Q_t}{Q_{t-1}}\right) - \sum_j \frac{1}{2}\left(S_{jt} + S_{jt-1}\right) In\left(\frac{X_{jt}}{X_{jt-1}}\right)$$

Where, QI_t is the total output index, XI_t is the total input index, and S_{jt} are factor shares of input j at time t.

The state-level time series data (1970-2000) on output, input use levels, prices of output and inputs, etc. were used to measure TFP growth for all major rice-producing states of India.

3. Results and discussion

The long-term trends in growth of rice yield by ecosystem and TFP growth were computed for two different periods viz., early GR period (Until 1985) and late GR period (After 1985) in order to examine changes that took place between these two periods[1].

Long-term yield growth by ecosystem and state

The long-tern yield trends for three major rice ecosystems were shown in Figure 1 along with estimated growth rates for the early GR and late GR periods. Irrigated ecosystem where availability of irrigation water is more reliable-mainly irrigated lowland and canal areas-accounts for 21 per cent of total rice area while 33 per cent is under other irrigation sources such as tanks, wells, command areas, etc (largely irrigated area). The remaining rice area of 46 per cent is under rainfed ecosystem-largely depends upon rainfall. As shown in Figure 1, a cross ecosystem yield trend shows that yield advances in rice, achieved during the GR era, started to increase at slower rate for intensive irrigated rice systems in the 1990s while rainfed-ecosystems have picked up during late GR period. Rice yields were nearly doubled between triennium ending 1969

[1] Total period was divided into two sub-periods for TFP analysis viz., until 1985 (early GR period) and after 1985 (late GR period). The reasons for choosing 1985 as a cut of point are a) Nearly 100% area of rice and wheat crops was covered with MVs and irrigation by the mid-eighties in the favorable irrigated environments. Further, incremental increase in input use levels have considerably declined between 1985 and 2000 as compared to early GR period in this region, b) MV adoption has picked tremendously in the rainfed ecosystems after the 1985, c) Many earlier studies reported either stagnation or decline in rice productivity after mid 1980s, and d) India's achieved self-sufficiency in food production during 1983 because of GR technologies.

and 1999 under the irrigated ecosystem, where farmers have adopted MVs of rice quickly with increased use of modern farm inputs during early GR period. However, growth rate of rice yield under irrigated ecosystem has been decelerated from 2.7 per cent per year during early GR period to 1.3 per cent per year during late GR period. It is, however, not unusual to experience yield plateau or deceleration in its growth in the progressive areas because every technology has got its own potential boundaries beyond which yield levels can not be increased with same or marginal improvements in technology/input (Pingali, *et al*, 1997).

Rice yields under the largely irrigated and rainfed areas are increasing at higher rate during late GR period than in the early GR period (Fig 1). Thus in contrast to the studies based on 'controlled environments'-as cited above (under 'Introduction section'), the long-term growth trends of yields under the farmers' fields (Figure 1) shows an increasing trend throughout GR period under all ecosystems, but the rate of increase in yields has declined after the mid 1980s only under irrigated ecosystem

The state-level yield trends of rice also shows an increasing trend in Andhra Pradesh, Tamil Nadu, Karnataka and Punjab (irrigated areas) which were the forerunners of the rice Green Revolution in India (Table 1). However, growth rate of rice yields slowed down in the 1990s-but not registered negative growth-in these states as MV adoption and irrigation coverage nearly complete. There was also less increase of input uses in the 90s as compared to the 70s and 80s in the irrigated states (Table 2). The states such as Assam, Bihar, Madhya Pradesh, West Bengal, etc, which were predominantly rainfed areas-have picked up with quantum jump in the growth of rice yields in the 1980s (Table 1). Yield growth has substantially slowed down even in some rainfed states during

1990s. For country as a whole, yield of rice has increased at annual compound growth of 2.3 per cent during 1971-2003, with maximum growth achieved in the 80s.

Use of chemical fertilizer per unit cropped area has substantially increased in irrigates states such as Andhra Pradesh and Punjab during early GR period as MV area as expanded rapidly, registering appreciable yield growth (Table 2). Growth in rice yields in the eastern India states Bihar and West Bengal-predominantly rainfed states-have picked up after 1980s with increased MV adoption

TFP growth

As discussed above, changes in physical yield are not true measures of productivity from efficiency perspective. Total factor productivity (TFP), is a true measure of economic efficiency. Table 3 reports growth rates of TFP for rice during early and late GR periods for major selected states. The TFP growth for rice was significantly higher in Punjab as expected during early GR period; however it slowed down drastically during late GR period. In Andhra Pradesh and Punjab states-which are the forerunners of rice GR, the TFP grew at an average rate of 1.2-1.3 per cent per annum during GR period. But the TFP growth declined rapidly between early and late GR periods in Punjab and Karnataka, implying that input growth was a principal source of output growth after mid 80s in these states. The estimates of TFP growth are closely comparable with earlier studies (Kumar and Mrithyunjaya, 1992; Rosegrant and Evenson, 1992, 1993 and 1995; Kumar and Rosegrant, 1994, Fan, et al, 1998).

While fertilizer use rapidly increased for rice in Punjab, labor use tremendously reduced between 70s and 80s (Table 2) that led to mechanization of Punjab agriculture over the period. Therefore higher rate of MV adoption, increased use of fertilizers and irrigation expansion were seems to be primary factors for TFP increases until mid 1980s while increased input uses were the main contributing factors after mid 80s in Punjab and Andhra Pradesh. On the contrary, TFP growth picked up in Bihar and Orissa (largely rainfed states) as MV adoption increased after 1980s in these states. In partially irrigated states such as Uttar Pradesh and West Bengal, TFP continued to increase, but it slowed down in the late GR period as compared in early GR period (Table 3). Further, it is reported that inter-state/regional movement (spillovers) of MVs from one state to other-largely from irrigated areas to rainfed states contributed to increased TFP growth in rainfed states such as Bihar, Orissa, and West Bengal after 1980s (Janaiah, 2004).

Results suggest that various modern technologies (such as MVs) developed and adopted by the farmers over the period have continued to make considerable impact on rice productivity growth-as reflected in the increasing TFP growth. However, rate of increase in TFP growth has started to decelerate under the irrigated ecosystem during the late GR period. This implies that 'level' of productivity impact of the successive generations of modern technologies (such as new MVs) has apparently been going down, which is not unusual to experience plateau or deceleration in TFP growth in the progressive areas because TFP levels can not be increased at the same rate during the late GR period as it was during the early GR period.

4. Conclusions

The paper analyzed the long-term yield growth of rice by ecosystem and state, and TFP growth for two period early GR (Until 1985) and late GR (After 1985). Detailed time-series data on required variables were obtained from secondary sources. A Tourvist-Theil index method applied for TFP estimation.

The long-term growth trends of yields shows an increasing trend throughout GR period under irrigated ecosystem (irrigated states) where MV adoption and irrigation coverage nearly complete. However yield growth slowed down during the late GR period under the irrigated ecosystem-but not registered negative growth while rainfed-ecosystems have picked up during late GR period.

TFP grew at average rate of 1.2-1.3 per cent per annum during GR period in the irrigated states such as Andhra Pradesh and Punjab. But, the TFP growth declined rapidly between early and late GR periods in Punjab and Karnataka. On the contrary, TFP growth picked up in the rainfed areas as MV adoption increased after 1980s.

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Table 1. Compound annual growth rates of yield for rice in major states of India

(percent per year)

Sate	Irrigated area (%), 1999	1971-1980	1981-1990	1991-2003	1971-2003
Andhra Pradesh	96	2.37	1.96	1.74	1.99
Tamil Nadu	94	0.11	5.79	1.36	2.40
Karnataka	71	1.48	0.39	1.32	1.27
Punjab	99	4.14	0.72	0.12	1.56
Uttar Pradesh	65	1.30	5.66	1.97	3.94
Assam	23	-0.03	1.69	1.42	1.52
Bihar	41	-0.20	5.02	5.23	1.80
Madhya Pradesh	23	-1.72	3.45	-3.82	1.50
Orissa	38	1.19	4.10	-2.88	1.71
West Bengal	26	1.70	6.20	1.37	2.73
AL INDIA	52	1.65	3.51	1.10	2.30

Table 2:Trend in input use levels for rice in the selected states of India

States	1971-76	1981-86	1996-2000
Andhra Pradesh			
MV area (%)	51	84	98
Organic manure (ton/ha)	5.8	6.4	3.4
Chemical fertilizer (kg/ha)	58.4	132.4	178.2
Labor (mandays/ha)	114.2	151	108.6
Pubjab			
MV area (%)	83	95.3	93
Organic manure (ton/ha)	4.1	6.3	1.6
Chemical fertilizer (kg/ha)	78	178.5	208.6
Labor (mandays/ha)	133	106	52
Bihar			
MV area (%)	18	32	73
Organic manure (ton/ha)	2.0	1.0	0.6
Chemical fertilizer (kg/ha)	8.5	31.2	92.0
Labor (mandays/ha)	94	109	120.6
West Bengal			
MV area (%)	18.6	36.6	78
Organic manure (ton/ha)	2.7	3.3	2.1
Chemical fertilizer (kg/ha)	12.0	33.5	96.8
Labor (mandays/ha)	113	141	108

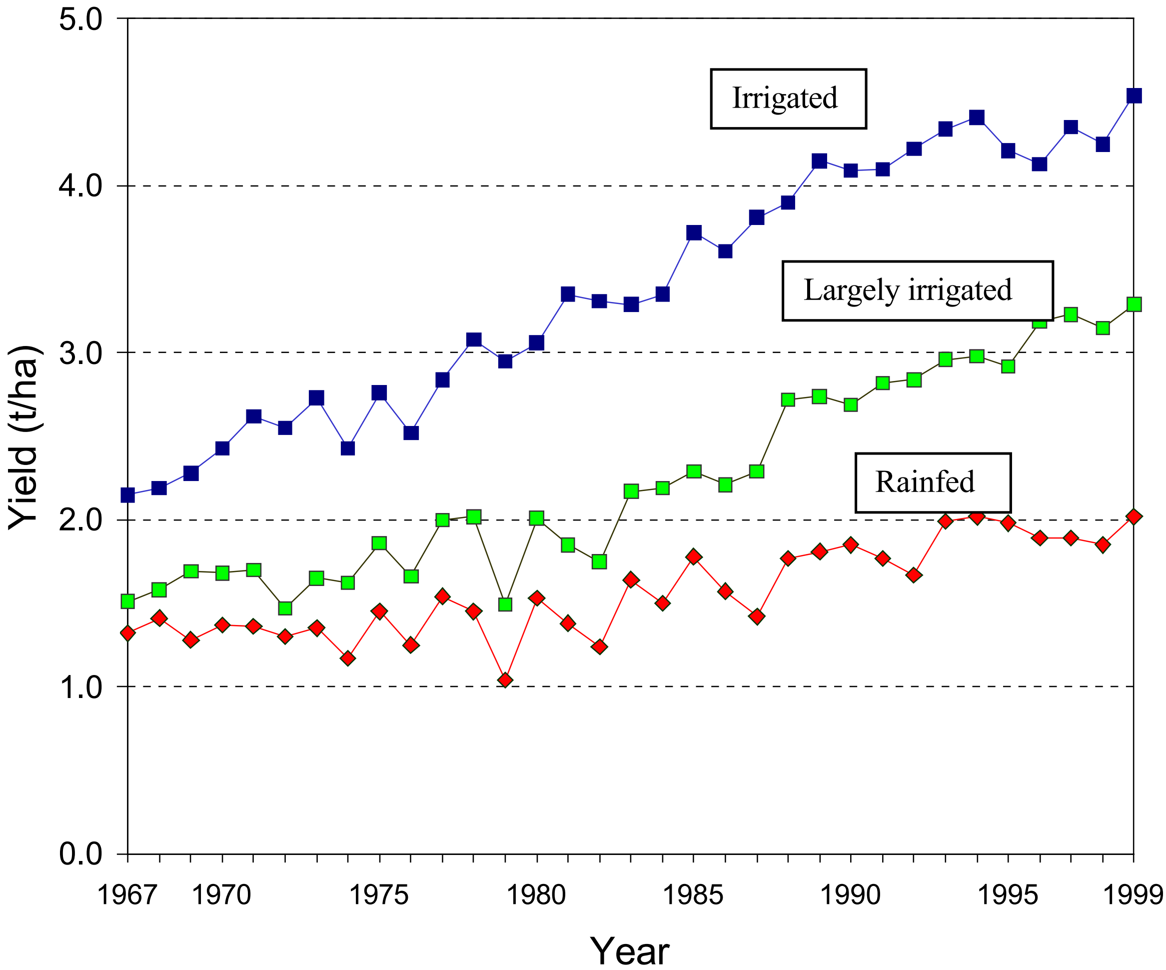
Table 3: Total factor productivity growth of rice in principal growing states

(percent per year)

State	Period	Output growth	Input growth	TFP growth
Andhra Pradesh	Early GR	2.85***	2.16**	0.69**
	Late GR	1.97**	0.01	1.96**
	Overall GR	2.43***	1.13**	1.30**
Karnataka	Early GR	-0.46	-1.51*	1.04**
	Late GR	2.44**	2.84***	-0.40
	Overall GR	1.28**	1.10*	0.18
Punjab	Early GR	4.72***	1.10**	3.62***
	Late GR	-0.92**	-0.12	-0.79*
	Overall GR	1.67***	0.44*	1.23**
Uttar Pradesh	Early GR	2.52***	0.05	2.48**
	Late GR	0.72*	0.14	0.58*
	Overall GR	1.51**	0.10	1.41**
Assam	Early GR	1.30*	0.53*	0.76*
	Late GR	0.91*	0.24	0.68*
	Overall GR	1.11*	0.39	0.72*
Bihar	Early GR	0.14	1.13*	-1.00*
	Late GR	3.79***	-0.57*	4.36***
	Overall GR	1.15*	0.66*	0.49*
Madhya Pradesh	Early GR	2.25**	1.15*	1.10*
	Late GR	0.81*	1.35**	-0.55*
	Overall GR	1.53**	1.25**	0.28
Orissa	Early GR	1.18*	0.96*	0.22
	Late GR	2.79***	0.44*	2.36**
	Overall GR	1.89**	0.73*	1.16**
West Bengal	Early GR	2.88**	1.00*	1.89**
	Late GR	2.07**	1.13*	0.94*
	Overall GR	2.49**	1.06*	1.43**

Note: ***, ** and * indicate 1%, 5% and 10% probability levels of significance respectively.

Fig 1. Trends in rice yield for irrigated and rainfed ecosystems, India, 1967-99



Ecosystem	Average yield (t/ha) 1967-69	1984-86	1997-99	Growth rate(%/yr) 1967-85	1985-99
Irrigated	2.21	3.56	4.38	2.7 (0.2)	1.3 (0.2)
Largely Irrigated	1.59	2.23	3.22	1.8 (0.4)	2.7 (0.3)
Rainfed	1.33	1.62	1.92	0.8 (0.5)	1.5 (0.4)

Note: The figure within parentheses is the standard error of the estimated growth rate.

Source: Directorate of Economics and Statistics, Ministry of Agriculture, India.

Definitions of ecosystems for this figure (Source: IRRI, The Philippines):
Irrigated ecosystem: Rice area of all districts with above 60% irrigated area
Largely irrigated ecosystem: Rice area of all districts with 40-60% irrigated area
Rainfed ecosystem: Rice area of all districts with less than 40% irrigated area