Economic Affairs
DOI : 10.5958/0976-4666.2015.00114.X

Estimation of Productivity and Efficiency of Rapeseed and Mustard Production in India

Sant Kumar and Md. Ejaz Anwer

ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi-12

Corresponding author: santkumar@ncap.res.in

Paper No.: 304 Received: 18 February 2015 Accepted: 20 December 2015

Abstract

This paper analyses the total factor productivity (TFP) growth and its components "technical change and technical efficiency change in production of rapeseed and mustard (R&M) in major states of India. The productivity growth has been estimated through data envelopment analysis (DEA) based Malmquist Productivity Index (MPI) for the period 1994-95 to 2011-12 for which recent data for selected states were available. Decomposition analysis of TFP change has revealed that output growth of R&M was driven by both technical change and technical efficiency change. This is further witnessed by the positive and significant growth of yield in increasing production of R&M. Regional pattern of productivity growth has revealed large interstate variations with states mean TFP change was 3.3%. Analysis of input use has shown lower growth during study period. Analysis has also shown that the share of current and capital inputs in total cost of cultivation has shrunk and input use efficiency has slowed down significantly (except Rajasthan). The study has concluded that the recent sloth in yield of R&M in study states could be due to inefficiency of input use rather than slowdown in technical change. The study calls for an increasing investments on research for development of high-yielding disease resistant and stress tolerant varieties and demonstration of location–specific good agricultural practices on farmers' fields to encourage adoption of improved practices. A combination of research and extension will lead to increase input use efficiency at farmers' fields and thereby sustaining growth in TFP.

Keywords: TFP growth, efficiency change, technical change, malmquist productivity index, rapeseed, mustard

The green revolution technologies (GRTs) adopted during mid-1960s backed with conducive policy environment, and public investment in rural infrastructure have significantly contributed to increased production of cereals, particularly of rice and wheat in India. This has immensely benefitted to achieving self-sufficiency in food production, increased output growth of several crops than their growth in demand, and raising trade surplus (export minus import) in food production (Chand *et al.* 2011). The main component of new farm technology was modern varieties (MVs) requiring intensive use of chemical inputs and irrigation. However, some empirical studies have reported that the MVs adopted during the period of green revolution have exhausted their potential to further increase in yield not only in India but across the globe (Hayami and Kikuchi, 1999). Further, the input-intensive modern agricultural practices have created multiple problems concerning sustainability of agriculture that include decline in productivity, depletion in soil micro-nutrients, degrading soil and water resources, emergence of new problems (diseases, pests, weeds), decrease in farm income, and change in climate and environment (Kumar and Chand, 2014).

A debate emerged in policy arena during mid-2010s and still being discussed that whether the slowdown in growth of agricultural sector was due to deceleration in technical change or policy failures (GoI, 2007; Narayanamoorthy, 2007). Moreover, the role of agriculture in economic development together with improving food and nutrition security and providing livelihood security is well documented. Also, the role of public investment in agricultural research in reducing poverty and bridging the rural-urban divide has been established (Fan *et al.* 2005). The total factor productivity (TFP) which is commonly used as synonymous with contribution of research or technical change has been measured to signify the role of research. In brief, the coefficient of TFP provides the idea of whether growth in productivity was due to technical change or technical efficiency change.

In the past, a number of studies have been undertaken to measure TFP growth for major crops like rice, wheat, maize and or crop groups like cereals, pulses, oilseeds, etc. (Kumar and Mruthyunjaya, 1992; Kumar and Rosegrant 1994; Chand *et al.* 2011). There has been no in-depth analysis to study productivity growth of major edible oilseeds like Rapeseed and Mustard (R&M) in recent past. The present study fills the void and attempts to examine TFP growth in production of R&M in India. The R&M crop is one of the major edible oilseeds and accounted for about 26% of total edible oilseeds produced in India during triennium ending (TE) 2013-14. The study has also examined use of inputs in production of R&M to establish the link whether the disruption in productivity growth is due to deceleration in input use.

The present paper is organized in five sections. After a brief introduction in section one, the section two provides the review of literature on measurement of productivity growth in agriculture. In section three, a brief profile of R&M production including data and methodology which describes data sources and variables and description of measurement of productivity and its components have been presented. Section four presents results and discussions describing trend in yield of R&M and factor productivity, trend in TFP growth, and technology fatigue or inefficiency in input use. Finally, in the last section, we conclude no evidence of technology fatigue but inefficiency that has retarded growth in yield of R&M.

A number of studies on measurement of productivity in agriculture have been made at national, state and crop-specific level. Some studies on productivity of Indian agriculture have shown that TFP growth was the main driving force of growth in agricultural sector during 1980s (Rosegrant and Evenson, 1992; Dholakia and Dholakia, 1993; Evenson *et al.* 1999; Fan *et al.* 1999). Some other studies on livestock sector have concluded positive and significant role of TFP in increasing output growth of livestock sector (Birthal *et al.* 1999; Avila and Evenson, 2010). Using micro-level data[1] a few crop specific-studies have also been made (Pinstrup *et al.* 1991; Sindhu and Byerlee, 1992; Kumar and Mruthyunjaya, 1992; Kumar and Rosegrant, 1994; Kumar *et al.* 1998; Joshi *et al.* 2003; Suresh, 2013). These studies confined mainly to major foodgrains like rice, wheat, maize, etc. Hence, the present study has attempted to estimate TFP growth of R&M production to understand recent trend in productivity in India.

Data and Methodology

India is one of the major edible oilseeds producing countries in the world. The country produced about 29 million tonnes (Mt) of edible oilseeds from an area of 25.4 million hectare (Mha) during TE 2013-14. The major edible oilseeds grown in India include R&M, groundnut, soybean, and sunflower. The R&M is a major *rabi* season edible oilseed and accounts for about 26 % of total edible oilseeds production in TE 2013-14. During the above period, production of R&M was 75.0 lakh tonnes, covering an area of 63.1 lakh hectares with yield of 1188 kg/ha at all-India level (Table 1). Regionally, this crop is concentrated in major growing states of Rajasthan (37.4%), Madhya Pradesh (12.1%), Uttar Pradesh (8.7%), Haryana (7.2%), West Bengal (5.8%), Assam (4.2%) and Gujarat (3.1%) in terms of area. These seven states together contributed to nearly 80 % of total area and about 94 % of total production of R&M in the country during TE 2013-14. There is a wide variation in yield of R&M, ranging from 592 kg/ha in Assam to 1663 kg in Gujarat. Also, people of northern and eastern regions of India prefer mustard oil, while people of western region prefer groundnut oil and people of southern region consume both groundnut and coconut oils.

The main objective of present study was to analyze the productivity and efficiency performance of R&M production in key producing states of India. As noted above, R&M is the major edible oilseeds produced in few states of India. The major states include Rajasthan, Haryana, Madhya Pradesh, Uttar Pradesh, Gujarat, West Bengal and Assam. The latest comparable average farm level data on output, inputs, and their prices were taken from the Reports of the Commission for Agricultural Costs and Prices (CACP), Ministry of Agriculture, Government of India, New Delhi, for the period 1992-93 to 2011-12. The missing year data on inputs, output and their prices were predicted using interpolations based on trends in available data. The data set included one output variable of yield (kg/ha), and six input variables viz. chemical fertilizers (NPK, kg/ha), manures (q/ha), animal labour (pair hour/ha), human labour (man-hour/ha), and cost of machine labour and irrigation[2]. To handle extreme fluctuations in input and output data, triennium averages were worked out. The analysis was done by using the software DEAP 2.1 (Coelli, 1996). The study has attempted to construct TFP indices, estimate growth rates and factors contributing to output growth in R&M production during the period 1994-95 to 2011-12 for which the recent data were available.

Most commonly used measures of productivity growth are single factor or multi factor productivity. The concept of multi or total factor productivity is more relevant in context of resource use efficiency. Over the past three decades, several theories and methods have been developed for measurement of TFP. In recent years, stochastic frontier analysis and Data Envelopment Analysis (DEA) based Malmquist Productivity Index (MPI) have become popular approaches that use panel data for estimation of TFP.

According to MPI approach, TFP can be increased not only due to technological change but also due to improvement in technical efficiency. The MPI approach has become quite popular because: (i) it requires no price data, and only quantity data is sufficient to run the model, (ii) it does not assume optimizing behavior of production unit, and (iii) it allows decomposition of productivity change into two components- technical change and technical efficiency change.

The Malmquist productivity index was introduced by Caves *et al.* (1982). The MPI based TFP index measures the optimum level of outputs that can be produced from a given technology (Coelli *et al.* 2005). It measures the radial distance of the observed output vectors in the period t and t+1 relative to a reference technology. The output-oriented MPI for the period t is written as (1):

$$M^{t} = \frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)} \qquad (1)$$

which is defined as the ratio of two output distance functions with respect to given technology in the period *t*. For the period t+1, another productivity index for a given technology can be depicted as;

$$M^{t+1} = \frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^t, y^t\right)} \qquad (2)$$

Since both equations are arbitrary, and since the two indexes are not necessary equal, it is conventional to define the MPI as geometric mean of two, and so;

$$M_0\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \left[\left(\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}\right)\left(\frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^t, y^t\right)}\right)\right] \qquad (3)$$

where, the notations x and y are the vector of inputs and outputs, D_0 represents the distance and M_0 represents the Malmquist Productivity Index (MPI). Fare *et al.* (1994) have decomposed the total productivity into two components, viz. technical change and efficiency change as indicated below:

$$\textit{Efficiency Change} = \left(\frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}\right) \qquad (4)$$

$$\textit{Technical Change} = \left[\left(\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}\right)\left(\frac{D_0^t\left(x^t, y^t\right)}{D_0^{t+1}\left(x^t, y^t\right)}\right)\right] \qquad (5)$$

The efficiency change can be further decomposed into pure efficiency change and scale efficiency change. A detailed account on the MPI can be had from Fare *et al.* (1994), Coelli *et al.* (2005), Bhushan (2005) and Chaudhary (2012).

Table 1: State-wise area, production and yield of R&M: TE 2013-14

(Area in lakh ha, production in lakh tonnes, and yield in kg/ha)

State	Area	Production	Yield
Assam	2.1 (4.2)	1.6 (2.1)	591.7
Gujarat	2.3 (3.1)	3.9 (5.2)	1663.4
Haryana	5.4 (7.2)	8.6 (11.5)	1585.3
Madhya Pradesh	7.7 (12.1)	8.8 (11.7)	1129.1
Rajasthan	28.0 (37.4)	35.3 (47.0)	1256.0
Uttar Pradesh	6.5 (8.7)	7.7 (10.2)	1170.7
West Bengal	4.4 (5.8)	4.4 (5.9)	1012.1
All India	**63.1 (100.0)**	**75.0 (100.0)**	**1188.0**

Note: Figures in parentheses are percentage of all-India.

Results and Discussion

There has been a significant increase in yield of R&M in past 18 years, about 37.0 % increase, from 847.6 kg/ ha to 1161.0 kg/ ha at all-India level during 1994-95 to 2013-14 (Table 2). A similar increase in yield per ha was also observed in study states cultivating R&M, though the magnitude of increase in yield varied widely from about 23 % in Assam to 53 % in Rajasthan between 1994-95 and 2013-14. At all-India level, yield of R&M has grown at the rate of about 2.0 % during above period. State-wise analysis has revealed that Rajasthan has recoded highest growth of 2.6%, followed by about 2.0 % in Gujarat and Madhya Pradesh and similar growth in Haryana, and Uttar Pradesh and West Bengal (about 1.5%, each). Analysis has also shown that annual growth of yield was positive both at all-India level and in study states at one per cent level of significance. The positive and significant growth of yield has witnessed that growth in R&M production was mainly driven by technical change which is represented by yield. Area growth in R&M growing states was negative, while it increased nearly 1% in Madhya Pradesh, Rajasthan and West Bengal during above period.

The trend in TFP change, technical change and technical efficiency change by states in production of R&M during the period 1994-95 to 2011-12 has been illustrated in Figure 1. It depicts that movement of TFP change was aligned more with movement in technical change/progress than that of technical efficiency change. The year-wise trend in technical change, technical efficiency change and TFP change in selected study states have been presented in Appendix 1.1 to 1.7.

Analysis has shown that mean TFP change of study states grew at the rate of about 3 % during the period 1994-95 to 2011-12 (Table 3). Decomposition analysis has revealed that growth in TFP change was contributed by both technical efficiency change and technical change (about 2.0%, each). These findings imply that production of R&M can be increased further by making improvement in technical efficiency (even at same level of input use) which is a management issue in close association of technical change which is positive and still rising.

Table 3 further depicts the TFP change and its components for study states. The growth in TFP change has been positive and varied across states; the highest being in West Bengal (5.7%), followed by Madhya Pradesh (4.8%), Haryana (4.6%) and lowest in Gujarat and Rajasthan (1.3%, each) during above period.

State-wise analysis has further shown that positive change in TFP was driven by both technical change and technical efficiency change. The technical efficiency change in state of Rajasthan was negative and this describes that production practices in use (i.e. efficiency change) could not catch-up with the technical change,

Table 2: Trend in yield of R&M in selected states: TE 1994-95 to 2013-14

States	Yield (kg/ha)		CAGR (%)	
	1994-95	2013-14	Yield	Area
Assam	482.3	591.7	0.7*	-0.64**
Gujarat	1108.3	1663.4	2.0*	-2.25
Haryana	1229.7	1585.3	1.6*	-0.09
Madhya Pradesh	828.0	1129.1	1.9*	1.2***
Rajasthan	807.4	1237.9	2.6*	1.1
Uttar Pradesh	908.0	1170.7	1.5*	-1.9*
West Bengal	766.3	1012.1	1.6*	1.2*
All-India	847.6	1161.0	1.9*	0.10

Note: (i) ***denotes significance at 10% level, **denotes significance at 5% level and *denotes significance at 1% level.

Table 3: State-wise trend in TFP and their constituents: TE 1994-95 to 2011-12

(per cent)

States	Efficiency Change	Pure Efficiency	Scale Efficiency	Technical Change	TFP Change
Assam	104.3	117.6	111.4	101.7	102.6
Gujarat	100.3	100.0	100.3	101.5	101.3
Haryana	101.6	100.0	101.6	102.1	104.6
Madhya Pradesh	102.5	100.0	102.5	102.0	104.8
Rajasthan	99.7	100.0	99.7	101.9	101.3
Uttar Pradesh	101.6	100.0	101.6	102.1	103.0
West Bengal	106.2	100.0	106.0	102.1	105.7
Mean (States)	**102.3**	**102.5**	**103.3**	**101.9**	**103.3**

consequently TFP change did not moved up. However, states of West Bengal (6.2%) and Madhya Pradesh (2.5%) showed higher technical efficiencies which helped in improving technical change and their by increase in TFP change. The similar trend was observed in case of wheat production in India during 1982-83 to 1999-2000 (Bhushan, 2005).

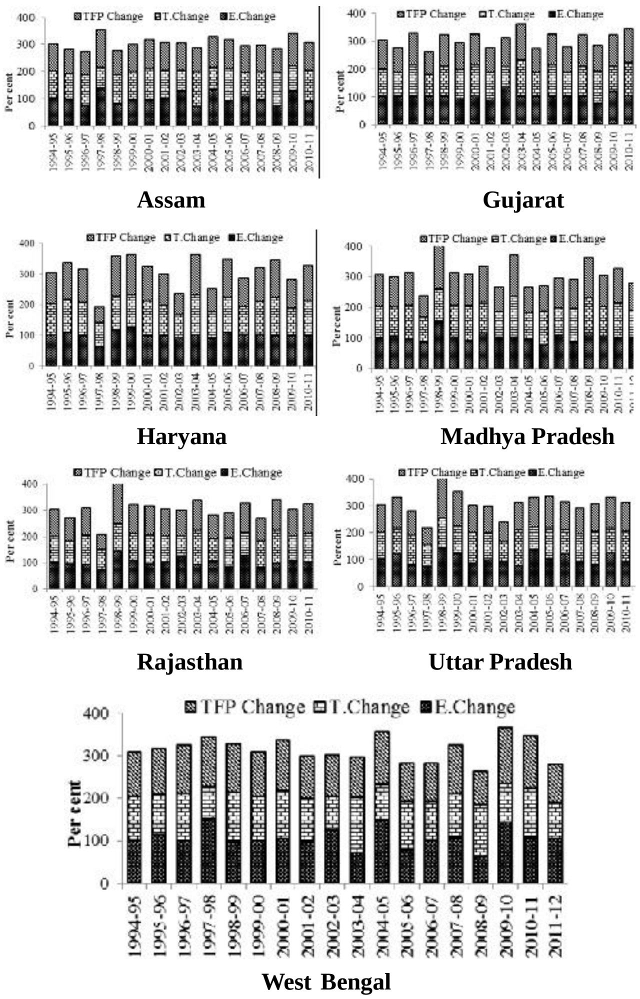

Fig. 1: Movement of indices of efficiency change, technical change and TFP change of rapeseed and mustard Production: 1998-99 to 2010-11.

As we know that technical efficiency is the product of its components "pure efficiency and scale efficiency. Analysis has shown that pure efficiency of R&M production across study states (except Assam) remained stagnant and equal to one during 1994-95 to 2011-12 (Table 3). It has also shown that with a positive change in scale efficiency, technical efficiency change remained above 1.0 and it implies that production technology being used has potential to increase output of R&M. The results suggest for increased attention about farm production practices and strategies being used and towards the factors that could influence the efficiency and technical change.

The growth in TFP and its components are presented here. Results have shown negative growth of TFP change in 4 out of 7 study states during the period 1994-95 to 2011-12 (Table 4). Data shows that in three states of Assam, Gujarat and Haryana; annual compound growth in TFP change was positive and poor.

The present study has clearly brought out that TFP growth has been the main source of increasing output growth of R&M in study states. Although, R&M is cultivated in selected states of India, therefore, it is important to analyze the growth in input use to increase production of R&M on sustained manner. The growth rates in use of inputs have been estimated for primary inputs namely irrigation, fertilizers, human labour, and machine labour covering the period 1994-95 to 2011-12.

Analysis has shown negative growth in use of human labour and machine labour in 3 out of 7 study states during 1994-95 to 2011-12 (Table 5). Analysis has further shown that in West Bengal, growth in machine labour was negative (-3.59%) which was replaced by use of human labour for which growth was positive and significant growth (2.94%). Data shows that compound annual growth in use of fertilizers have been positive and significant, though the growth in magnitude varied widely across study states. Growth in use of irrigation in production of R&M has been very poor and negative in half of the study states. The poor and negative growth in irrigation in production of R&M can be described from

Table 4: State-wise compound annual growth rates in efficiency change, technical change and TFP change: 1994-95 to 2011-12

States	Efficiency Change	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
Assam	0.58	0.07	-0.97	1.56	0.65
Gujarat	0.12	0.23	0.00	0.12	0.35
Haryana	0.06	0.04	0.00	0.06	0.10
Madhya Pradesh	-0.28	0.15	0.00	-0.28	-0.13
Rajasthan	-0.15	0.12	-0.01	-0.16	-0.03
Uttar Pradesh	-0.33	-0.01	0.00	-0.34	-0.34
West Bengal	-0.54	0.08	0.01	-0.56	-0.46

Table 5: Growth in input use in R&M production in study states during TE 1994-95 to 2011-12

State	Human Labour	Machine Labour	Fertilizers	Irrigation
Assam	0.24	0.15	9.60*	-4.42*
Gujarat	-0.46	-0.06	3.28*	-5.87*
Haryana	-0.33	0.23	3.94*	-0.10
Madhya Pradesh	0.58	-2.26	0.24	0.36
Rajasthan	-0.70	-1.45*	3.31*	-1.24
Uttar Pradesh	0.36	0.41	1.40*	0.73
West Bengal	2.94*	-3.59	2.81*	0.29

Notes:

1. Fertilizer (nutrients) in kg, human labor in man hours, and irrigation and machine labors in nominal price. The cost of irrigation and machine labor was deflated by diesel price to arrive at constant terms. Thereafter, triennium ending (TE) averages were worked out and growth was estimated. Pre, post and all period refers to year 1998-99 to 2004-05, 2005-06 to 2010-11 and 1998-99 to 2010-11, respectively.
2. '*' denotes level of significance at 1 %.

Table 6: Trend in cost and factor share and growth of input used in R&M production

States	Input Groups	Cost Share (%)		Factor Share (%)		Growth Rate (%)#
		1994-95	2011-12	1994-95	2011-12	
Assam	Current	9.4	9.1	8.8	8.1	9.3
	Capital	29.3	27.4	27.4	30.8	8.4
	Labour	45.7	49.7	42.7	44.2	7.8
	Land	22.5	19.0	21.0	16.9	6.8
Gujarat	Current	5.9	6.3	10.6	12.1	6.2
	Capital	22.3	17.9	39.6	34.2	6.6
	Labour	11.3	11.3	20.1	21.7	5.8
	Land	16.8	16.7	29.8	31.9	7.5
Haryana	Current	6.9	5.5	10.2	9.6	7.2
	Capital	19.7	15.2	29.1	26.5	8.8
	Labour	12.1	10.3	17.9	18.0	8.6
	Land	29.1	26.2	42.8	45.8	8.3
Madhya Pradesh	Current	7.9	6.8	11.6	11.3	5.4
	Capital	27.8	17.4	40.9	28.8	5.8
	Labour	8.6	11.1	12.6	18.4	9.0
	Land	23.7	25.0	34.8	41.4	9.1
Rajasthan	Current	4.9	5.8	10.3	9.7	7.1
	Capital	18.4	19.9	38.5	33.0	8.4
	Labour	9.6	17.9	20.2	29.6	7.4
	Land	14.8	16.7	31.1	27.7	8.4
Uttar Pradesh	Current	11.7	9.1	17.1	11.6	3.5
	Capital	15.5	24.9	22.6	31.7	8.9
	Labour	15.2	17.7	22.1	22.5	6.7
	Land	26.2	26.9	38.2	34.2	7.4
West Bengal	Current	19.9	12.7	17.5	14.1	6.0
	Capital	29.0	18.3	25.6	20.2	7.3
	Labour	39.0	34.3	34.4	37.9	8.6
	Land	25.4	25.1	22.4	27.7	9.8

Notes: * refers at 1 % level of significance. # indicates for the period 1994-95 to 2011-12.

the fact that production of R&M requires less irrigation as compared to same season crop like wheat and farmers' expect that winter rainfall can meet the requirements. However, sometime winter rainfall is not sufficient to grow R&M crop successfully.

To have further in-depth analysis on cultivation cost, the various inputs used in production of R&M were classified into four sub-groups: current inputs, capital inputs, labour, and land[3]. The share of above four sub-groups of inputs has been summarized on three aspects – share of inputs in the total cost of cultivation (cost share), their share in total value of output (factor share), and growth in expenditure (nominal) on these inputs groups (Table 6).

Analysis has shown that growth in use of current inputs has been lower than that of land during study period, except in Assam. The lower growth in expenditure on current inputs shows that farmers are feeling inconvenient in application of fertilizers, irrigation and other current inputs and which is reflected through poor and negative change in technical efficiency in study states (Table 4).

The expenditure on capital inputs has reduced significantly in study states (except Uttar Pradesh), the highest in Madhya Pradesh and West Bengal (above 10.0%, each) and lowest in Assam (1.9%) between 1994-95 and 2011-12. The reduction in growth of capital investment is a matter of concern, as these inputs have long-term implications for output growth and consequently resulting into poor farm income of the farmers.

Corresponding to the relative growth in expenditure of inputs, the cost structure has depicted a mixed trend over time. While the expenditure shares of current inputs have declined in majority of states (except Gujarat and Rajasthan) in TE 2011-12 over 1994-95, the results for land and labour inputs have increased during above period. In other study, decline in capital and land costs and increase in labour cost have been reported by 13 percentage points in paddy cultivation at all-India between 1980-81 and 2009-10 (Suresh, 2013). The surge in expenditure on labour can be explained in the light of usual increase in agricultural wages in recent years than that of their physical use in cultivation of crops, be it R&M or labour intensive crop like rice. Increased expenditure share on land and labour can be explained from the fact that these inputs have high opportunity to be used in almost risk free crop like wheat grown in same season in selected states as main staple cereal. In fact, it is not wheat is a primary competing crop for R&M, but it is R&M competes for area to be sown under it in *rabi* season. Although minimum support price for R&M have been increased during TE 2007-08 to 2012-13 by 40.5 %, while area under R&M has fallen by (-) 3.7 %. This indicates that price alone cannot increase the performance (area and output) of R&M and other such oilseeds and pulse crops, the combination of both technology and price support can favour to enhance output growth on sustained basis.

Conclusion

Measurement of TFP growth and its components viz., technical efficiency and technical change have been made in selected study states producing R&M using DEA based MPI for the period 1994-95 to 2011-12. Analysis has revealed large inter-state variation in yield exists and production of R&M was mainly led by increase in yield during period of study. Analysis has further revealed that both technical change and technical efficiency change (about 2%, each) have contributed to TFP change to the tune of 3.3 %. All the study states have exhibited positive TFP change during the period under study. This positive TFP change in selected states was resulted due to positive technical change and efficiency change (except Rajasthan). Further, major R&M producing states of Madhya Pradesh, Rajasthan, Uttar Pradesh and West Bengal have exhibited negative annual growth in TFP change during period under study. The negative growth in TFP was mainly due to negative annual growth in efficiency change, a component of TFP measurement. The study has noticed significant decline in growth in use of current inputs like irrigation, fertilizers, and human labour during overall study period. The study has further noticed that while the expenditure shares of current and capital inputs have declined, the shares of land and labour have increased during overall period. Decline in capital inputs suggest to increase long-term investment as these have long-term effect on production performance.

The empirical findings brought out by this study have confirmed that there is no sign of conclusive evidence for deceleration in technology/ technical progress in case of R&M production during the study period. However, growth in application of current inputs has declined over time. Therefore, it is not the technical change, rather inefficiency in input use that is contributing to decline in yield and output growth of R&M. The combination of technical change, improved practices and input policies should be taken altogether to improve the output growth of R&M on sustained basis.

Notes

[1] Micro-level average farm data were collected under the 'Comprehensive Scheme for the study of Cost of Cultivation of Principal Crops', Directorate of Economics and Statistics, Ministry of Agriculture, Government of India.

[2] The nominal cost of machine labour and irrigation were converted into real cost by deflating with price index for diesel.

[3] Current inputs were seed, fertilizer, manure, insecticides, interest on variable cost; Capital inputs were draft animal, irrigation, machinery, depreciation, interest on fixed capital; Labour input was human labour. The land revenue involved the value of land resources (both owned and hired) as well as other charges on land.

References

Avila, A.F.D. and Evenson, R.E. 2010. *Total factor productivity growth in agriculture: The role of technological capital*. Handbook of Agricultural Economics, Vol. 4 Burlington: Academic Press, pp. 3769-3822.

Bhushan, S. 2005. Total factor productivity growth of wheat in India: A Malmquist Approach. *Indian Journal of Agricultural Economics*, **60**(1): 32-48.

Birthal, Pratap S., Kumar, A, Ravishankar, A. and Pandey, U.K. 1999. *Sources of growth in livestock sector*. Policy Paper No. 9, New Delhi: National Centre for Agricultural Economics and Policy Research. New Delhi.

Caves, Douglas W., Christensen, Laurits R. and Diewert, W. Erwin. 1982. The economic theory of index numbers, and the measurement of input, output and productivity, *Econometrica*, **50**(6): 1393-1414.

Chand, R., Kumar, P. and Kumar, S. 2011. *Total factor productivity and contribution of research investment to agricultural growth in India.* Policy Paper 25, New Delhi: National Centre for Agricultural Economics and Policy Research.

Coelli, T.J. 1996. A guide to DEAP version 2.1: A Data Envelopment Analysis (Computer Program), Centre for Efficiency and Productivity Analysis, University of New England, Australia.

Coelli, T.J., Rao, D.S.P., Donnell, C.J. and Battese, G.E. 2005. *An introduction to efficiency and productivity analysis,* Springer, New York, USA.

Chaudhary, S. 2012. *Trend in total factor productivity in Indian agriculture: State level evidence using non-parametric Sequential Malmquist Index.* Working Paper No. 215. Centre for Development Economics, Delhi School of Economics, New Delhi.

Dholakia, R.H. and Dholakia, B.H. 1993. Growth of total factor productivity in Indian agriculture. *Indian Economic Review*, **28**(1): 25-40.

Evenson, R.E., Pray, C. and Rosegrant, M.W. 1999. *Agricultural research and productivity growth in India*. Research Report No. 109. Washington, D.C: International Food Policy Research Institute.

Fan, S., Connie Chan-Kang and Mukherjee, Anit. 2005. Rural and urban dynamics and poverty: Evidence from China and India. FCND Discussion Paper 196, Washington, D.C: International Food Policy Research Institute.

Fan, S., Hazell, P.B.R. and Thorat, S. 1999. *Linkages between government spending, growth and poverty in rural India*. Research Report No. 110. Washington, D.C: International Food Policy Research Institute.

Fare, R. C., Grosskopf, S. Morris, M. and Zhang, Z. 1994. Productivity growth, technical; progress, and efficiency change in industrialized countries. *The American Economic Review*, 66-83.

GoI. 2007 *Report of the Steering Committee on Agriculture for Eleventh Five-Year Plan (2007-12)*, Planning Commission, Government of India.

Hayami, Y. and Kikuchi, M. 1999. The three decades of green revolution in a Philippine village. *Japanese Journal of Rural Economics* **1**:10-24.

Joshi, P.K., Joshi, L. Singh, R.K., Thakur, J. Singh, K. and Giri, A.K. 2003. *Analysis of productivity changes and future sources of growth for sustaining rice-wheat cropping system*. National Agricultural Technology Project (PSR 15; 4.2), New Delhi: National Centre for Agricultural Economics and Policy Research.

Kalirajan, K.P. and Shand, R.T. 1997. Sources of output growth in Indian agriculture. *Indian Journal of Agricultural Economics*, **52**(4): 693-706.

Kumar, P. and Mruthyunjaya. 1992. Measurement and analysis of total factor productivity growth in wheat. *Indian Journal of Agricultural Economics,* **47**(7): 451-458.

Kumar, P. and Rosegrant, M. W. 1994. Productivity and sources of growth for rice in India, *Economic and Political Weekly* **29**(52): A183-A188.

Kumar, P. and Mittal, S. 2006. Agricultural productivity trends in India: Sustainability issues. *Agricultural Economics Research Review*, **19**(Conference Number): 71-88

Kumar, P. 2001. Agricultural performance and productivity, In: *Indian Agricultural Policy at the Crossroads*, Eds: S.S. Acharya and D.P. Chaudhri, New Delhi: Rawat Publications.

Kumar, P., Kumar, A. and Shiji, C.P. 2004. Total factor productivity and economic impacts of fisheries technology in India. *Agricultural Economics Research Review* **17**(Conference number): 131-144.

Kumar, P., Joshi, P.K., Johansen, C. and Asokan, M. 1998. Sustainability of rice-wheat based cropping system in India. *Economic and Political Weekly* **33**: A-152-A-158.

Kumar, P., Jha, D., Kumar, A., Chaudhary, M.K., Grover, R.K., Singh, R.K., Singh, R.K.P., Mitra, A., Joshi, P.K., Singh, Alka., Badal, P.S., Mittal, S. and Ali, J. 2002. *Economic analysis of total factor* *productivity of crop sector in the Indo-Gangetic Plain of India by district and region.* NATP Project under Irrigated Agro Ecosystem, Production System Research, Indian Council of Agricultural Research, New Delhi.

Kumar, Sant and Chand, Ramesh. 2014. *Research resource allocation across disciplines and states in Indian Agriculture: An Illustration using composite scoring approach*. New Delhi: National Centre for Agricultural economics and Policy Research, Mimeo.

Narayanamoorthy, A. 2007. Deceleration in agricultural growth: Technology or policy fatigue. *Economic and Political Weekly* **42**(25): 2375-79.

Pinstrup, Andersen P., Jaramillo, M., Hazell, P.B.R. and Ramasamy, C. (Eds). 1991. *The impact of technological change in rice production on food consumption and nutrition. The green revolution reconsidered: The impact of high-yielding rice varieties in south India*, 85-104. Johns Hopkins University Press; Maryland: USA.

Rosegrant, M.W. and Evenson, R.E. 1992. Agricultural productivity and sources of growth in South Asia, *American Journal of Agricultural Economics* **74**(3): 757-61.

Rosegrant, M.W. and Evenson, R.E. 1995. Total factor productivity and sources of long-term growth in Indian agriculture, *International Food Policy Research Institute*, Washington, EPTD Discussion Paper No. 7.

Sidhu, D.S. and Byerlee, D. 1992. Technical change and wheat productivity in the Indian Punjab in Post-GR Period. Working Paper 92-02, Economics, Mexico: CIMMYT.

Suresh, A. 2013. Technical change and efficiency of rice production in India: A Malmquist Total Factor Productivity Approach, *Agricultural Economics Research Review* **26**(Conference Number): 109-118.

Appendix

Appendix 1.1. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency and TFP Change in R&M in Assam: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.003	1.013	1.005	0.998	1.015
1995-96	0.988	0.915	2.361	0.419	0.904
1996-97	0.745	1.143	1.000	0.745	0.851
1997-98	1.694	0.790	0.504	3.360	1.338
1998-99	0.801	1.083	1.984	0.404	0.867
1999-00	0.946	1.052	1.000	0.946	0.995
2000-01	0.950	1.144	1.000	0.950	1.087
2001-02	1.028	1.014	1.000	1.028	1.043
2002-03	1.270	0.779	1.000	1.270	0.990
2003-04	0.664	1.314	1.000	0.664	0.873
2004-05	1.330	0.844	1.000	1.330	1.122
2005-06	0.929	1.167	1.000	0.929	1.084
2006-07	1.078	0.892	1.000	1.078	0.961
2007-08	0.970	1.018	1.000	0.970	0.988
2008-09	0.718	1.233	0.335	2.144	0.885
2009-10	1.281	0.931	2.986	0.429	1.192
2010-11	0.915	1.126	1.000	0.915	1.031
2011-12	1.469	0.847	1.000	1.469	1.244
Mean	**1.043**	**1.017**	**1.176**	**1.114**	**1.026**

Appendix 1.2. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency and TFP Change in R&M in Gujarat: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.000	1.010	1.000	1.000	1.010
1995-96	1.000	0.865	1.000	1.000	0.865
1996-97	1.000	1.134	1.000	1.000	1.134
1997-98	1.000	0.795	1.000	1.000	0.795
1998-99	1.000	1.108	1.000	1.000	1.108
1999-00	0.928	1.033	1.000	0.928	0.958
2000-01	0.978	1.137	1.000	0.978	1.112
2001-02	0.868	1.006	1.000	0.868	0.873
2002-03	1.270	0.810	1.000	1.270	1.029
2003-04	1.000	1.300	1.000	1.000	1.300
2004-05	1.000	0.857	1.000	1.000	0.857
2005-06	1.000	1.114	1.000	1.000	1.114
2006-07	1.000	0.879	1.000	1.000	0.879
2007-08	1.000	1.104	1.000	1.000	1.104
2008-09	0.769	1.156	1.000	0.769	0.889
2009-10	1.186	0.922	1.000	1.186	1.093
2010-11	1.020	1.177	1.000	1.020	1.201
2011-12	1.042	0.868	1.000	1.042	0.904
Mean	**1.003**	**1.015**	**1.000**	**1.003**	**1.013**

Appendix 1.3. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency and TFP Change in R&M in Haryana: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.016	1.012	1.000	1.016	1.028
1995-96	1.117	1.067	1.000	1.117	1.192
1996-97	1.000	1.079	1.000	1.000	1.079
1997-98	0.652	0.763	1.000	0.652	0.498
1998-99	1.202	1.093	1.000	1.202	1.313
1999-00	1.276	1.042	1.000	1.276	1.330
2000-01	1.000	1.126	1.000	1.000	1.126
2001-02	1.000	1.002	1.000	1.000	1.002
2002-03	0.887	0.779	1.000	0.887	0.691
2003-04	1.020	1.303	1.000	1.020	1.328
2004-05	0.895	0.863	1.000	0.895	0.772
2005-06	1.118	1.126	1.000	1.118	1.258
2006-07	1.047	0.895	1.000	1.047	0.936
2007-08	1.056	1.053	1.000	1.056	1.113
2008-09	1.000	1.238	1.000	1.000	1.238
2009-10	1.000	0.906	1.000	1.000	0.906
2010-11	1.000	1.139	1.000	1.000	1.139
2011-12	1.000	0.886	1.000	1.000	0.886
Mean	**1.016**	**1.021**	**1.000**	**1.016**	**1.046**

Appendix 1.4. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency and TFP Change in R&M in Madhya Pradesh: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.016	1.013	1.000	1.016	1.029
1995-96	1.044	0.953	1.000	1.044	0.996
1996-97	0.975	1.091	1.000	0.975	1.064
1997-98	0.874	0.797	1.000	0.874	0.697
1998-99	1.503	1.102	1.000	1.503	1.657
1999-00	1.022	1.041	1.000	1.022	1.064
2000-01	0.909	1.144	1.000	0.909	1.040
2001-02	1.165	1.010	1.000	1.165	1.176
2002-03	1.039	0.794	1.000	1.039	0.825
2003-04	1.033	1.314	1.000	1.033	1.357
2004-05	0.960	0.864	1.000	0.960	0.830
2005-06	0.754	1.106	1.000	0.754	0.834
2006-07	1.093	0.892	1.000	1.093	0.975
2007-08	0.858	1.103	1.000	0.858	0.947
2008-09	1.118	1.183	1.000	1.118	1.322
2009-10	1.077	0.944	1.000	1.077	1.017
2010-11	0.996	1.137	1.000	0.996	1.132
2011-12	1.022	0.877	1.000	1.022	0.897
Mean	**1.025**	**1.020**	**1.000**	**1.025**	**1.048**

Appendix 1.5. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency and TFP Change in R&M in Rajasthan: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.001	1.013	1.000	1.001	1.014
1995-96	0.926	0.915	1.000	0.926	0.858
1996-97	0.899	1.143	1.000	0.899	1.031
1997-98	0.753	0.790	1.000	0.753	0.574
1998-99	1.402	1.083	1.000	1.402	1.536
1999-00	1.068	1.052	1.000	1.068	1.109
2000-01	0.943	1.144	1.000	0.943	1.076
2001-02	1.021	1.014	1.000	1.021	1.030
2002-03	1.206	0.779	1.000	1.206	0.978
2003-04	0.912	1.314	1.000	0.912	1.183
2004-05	1.042	0.844	1.000	1.042	0.911
2005-06	0.830	1.167	1.000	0.830	0.936
2006-07	1.260	0.892	1.000	1.260	1.122
2007-08	0.776	1.018	1.000	0.776	0.831
2008-09	0.976	1.233	1.000	0.976	1.200
2009-10	1.073	0.931	1.000	1.073	1.013
2010-11	1.007	1.126	0.976	1.031	1.122
2011-12	0.847	0.847	1.025	0.827	0.718
Mean	**0.997**	**1.019**	**1.000**	**0.997**	**1.013**

Appendix 1.6. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency and TFP Change in R&M in Uttar Pradesh: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.008	1.012	1.000	1.008	1.020
1995-96	1.187	0.979	1.000	1.187	1.162
1996-97	0.798	1.123	1.000	0.798	0.896
1997-98	0.749	0.813	1.000	0.749	0.609
1998-99	1.471	1.089	1.000	1.471	1.601
1999-00	1.219	1.040	1.000	1.219	1.267
2000-01	0.879	1.138	1.000	0.879	1.000
2001-02	0.988	1.014	1.000	0.988	1.002
2002-03	0.902	0.779	1.000	0.902	0.703
2003-04	0.783	1.315	1.000	0.783	1.030
2004-05	1.373	0.823	0.983	1.397	1.131
2005-06	1.000	1.167	1.018	0.982	1.166
2006-07	1.192	0.894	1.000	1.192	1.066
2007-08	0.913	1.055	1.000	0.913	0.963
2008-09	0.826	1.233	1.000	0.826	1.018
2009-10	1.261	0.907	1.000	1.261	1.144
2010-11	0.920	1.151	1.000	0.920	1.059
2011-12	0.821	0.847	1.000	0.821	0.696
Mean	**1.016**	**1.021**	**1.000**	**1.016**	**1.030**

Appendix 1.7. Trend in Technical Change, Efficiency Change, Pure Efficiency, Scale Efficiency, and TFP Change in R&M in West Bengal: TE 1994-95 to 2011-12

Year (TE)	Technical Efficiency	Technical Change	Pure Efficiency	Scale Efficiency	TFP Change
1994-95	1.026	1.013	1.000	1.026	1.039
1995-96	1.136	0.944	1.000	1.136	1.072
1996-97	0.989	1.128	1.000	0.989	1.116
1997-98	1.513	0.762	1.000	1.513	1.153
1998-99	0.984	1.147	1.000	0.984	1.129
1999-00	0.985	1.052	1.000	0.985	1.036
2000-01	1.044	1.137	1.000	1.044	1.187
2001-02	0.984	1.006	1.000	0.984	0.990
2002-03	1.229	0.802	1.000	1.229	0.985
2003-04	0.714	1.311	0.937	0.762	0.937
2004-05	1.491	0.830	1.067	1.398	1.238
2005-06	0.779	1.150	1.000	0.779	0.895
2006-07	1.027	0.888	1.000	1.027	0.912
2007-08	1.061	1.055	1.000	1.061	1.120
2008-09	0.638	1.219	1.000	0.638	0.777
2009-10	1.411	0.924	1.000	1.411	1.304
2010-11	1.066	1.162	1.000	1.066	1.239
2011-12	1.046	0.853	1.000	1.046	0.892
Mean	**1.062**	**1.021**	**1.000**	**1.060**	**1.057**