Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

ISSN: 0972-6268	Vol. 13	No. 3	pp. 607-612	2014

Original Research Paper

Research on Agricultural Technology Efficiency in Consideration of Non-Point Source Pollution: The Data from China

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 14-7-2014
Accepted: 2-8-2014

Key Words:
Agricultural TFP
Non-point source pollution
Technology efficiency
Environmental protection

ABSTRACT

This investigation took the non-point source pollution into the analysis framework of agricultural total factor productivity (TFP), using Malmquist-Luenberger productivity index to measure the agricultural TFP of various regions in China from 2001 to 2011. The results showed that in the past 11 years, the agricultural TFP of China has increased rapidly, and technological progress was the major contributor, rather than the technical efficiency. The average annual growth rate of agricultural TFP when considering the environmental pollution was significantly lower than the value without considering environmental contamination. It indicated that environmental pollution had caused a greater loss of agricultural development efficiency in China. Seen from the comparisons among eastern, central and western regions of China, the agricultural TFP of eastern region was significantly higher than that of the central and western regions. The differences of agricultural TFP in different provinces were significant, the growth of agriculture was mainly dependent on input amount of resources, which resulted in the progressive degradation of agricultural production environment.

INTRODUCTION

During the reform and opening up of past 30 years, great changes have taken place in the agriculture and rural economy of China. The agricultural output has increased greatly and rural infrastructure construction has been strengthened significantly. However, Chinese agriculture is also facing with serious environmental problems caused by the extensive use of chemical industrial products. The census results from Chinese government showed that the pollution of agricultural sources has become the major sources of environmental pollution. Since the industrial pollution has been preliminarily controlled, the control of agriculture pollution becomes the key factor of environmental protection. Agricultural development should take full account of the carrying capacity of resources and environmental issues (Zhang Jie et al. 2014).

On the whole, the agricultural output growth of China is still a kind of investment-driven growth, i.e., extensive growth. Fan (1991) pointed out that more than half of China's agricultural growth was driven by the factor input, rather than by the growth of agricultural total factor productivity. Similarly, Scott & Huang (2005) noted that the agricultural output growth of China in the past 20 years mainly relied on factor input. For China, which is under the multiple constraints of relatively more scarcity of agricultural resources and human capital, and the deterioration of ecological environment, the contradiction between agricultural development and ecological environment will increase, long-term sustainable development can be achieved through extensive growth mode. Therefore, China's agricultural growth must rely on the improvement of production efficiency. Johnson & Richard (1997) pointed out that in developing countries such as China, agricultural productivity was the core of national wealth growth.

The traditional growth theory focuses on analysing the relationship between resource conservation and economic growth, and the framework of total factor productivity (TFP) provides an appropriate analytical tool to coordinate the relationship between them. But, with the increase of environmental problems, the research on how to introduce environmental factor on the basis of achieving economic development is relatively rare (Jiansheng Zhang et al. 2014). Therefore, based on the traditional TFP researches, the environmental factor was introduced in the paper, and then the agricultural growth under the constraint of environmental pollution was comprehensively studied, and lastly an empirical analysis using the data from China was carried out.

LITERATURE REVIEW (EARLIER STUDIES)

In recent years, many scholars have calculated the agricultural TFP of China. Wang et al. (2010) used Malmquist index to measure the agricultural TFP of various regions in China from 1992 to 2007, and established a spatial economy model for the empirical analysis of the factors which influenced the agricultural TFP in China. Using the provincial panel data from 1985 to 2007, Guo & Li (2009) measured and decomposed the agricultural TFP based on the nonparametric Malmquist index method of DEA. The results showed that from 1985 to 2007, the agricultural TFP of China kept growth which was caused by the technological advances in agriculture. Zhang & Liu (2012), considering the influence of random factors on Chinese agricultural production activities, used stochastic frontier analysis (SFA) method to measure the agricultural TFP of various regions in China from 1980 to 2009, and the results showed that technological progress of agriculture was the main driving force to promote agricultural TFP growth of China. Jin & Jian (2013) measured and analysed the agricultural TFP growth of China by using the nonparametric DEA-Malmquist index method. The results showed that agricultural TFP had maintained growth for long time, but still was in fluctuations mainly due to climate change. Although different methods and different data samples were adopted by many scholars, the conclusions were similar that since the reform and opening up, China has achieved rapid growth in agricultural TFP, but along with the character of periodic fluctuation. Seen from the source of growth, TFP growth was mainly contributed by the advances in technology, and technical efficiency was deteriorating essentially.

Overall, regarding the researches on the fluctuation feature of TFP in China, the literature has roughly divided the agricultural TFP growth since the reform and opening up into five stages: 1978-1984, 1984-1991, 1992-1996, 1997-2000 and after 2001, and it is generally believed that 1992 is an important turning point and there is an apparent feature of periodic fluctuation during these five stages. In the first stage TFP grows rapidly and in the second stage falls into stagnation or even recession, in the third stage it goes up again, in the fourth stage slows down significantly, and in the fifth stage reaccelerates growth. What factors influence agricultural TFP growth in China? Many researches explained it from the perspective of institutional change, which considered that the household contract responsibility system, rural industrial development, the release of price system and other systems had released the rural vitality and promoted the growth of agricultural TFP (Qiao et al. 2006, Xi & Peng 2010). In addition to system variables, there are some other factors that will affect the growth of agricultural TFP: (1) Human capital, which is a special factor of production with not only a direct effect of production factor but also an indirect productivity effect owing to its positive externalities (Zhang & Liu 2006). (2) Natural factors and climate change (Zhang & Carter 1997). (3) Infrastructure construction and R & D investment (Fan & Pardey 1997).

MATERIALS AND METHODS

In order to take the resources and environmental pollution into the analytical framework, a production possibilities set, which includes both "good" outputs and "bad" outputs need to be built, i.e., the environmental technology. Assuming that each province uses N kinds of inputs as $X = (x_1, x_2, \cdots, x_N) \in R_+^N$, and produces M kinds of "good output" with $Y = (y_1, y_2, \cdots, y_N) \in R_+^M$ and I kinds of "bad output" with $U = (u_1, u_2, \cdots, u_N) \in R_+^I$, then the environmental technology can be converted into the following model (Wang et al. 2008).

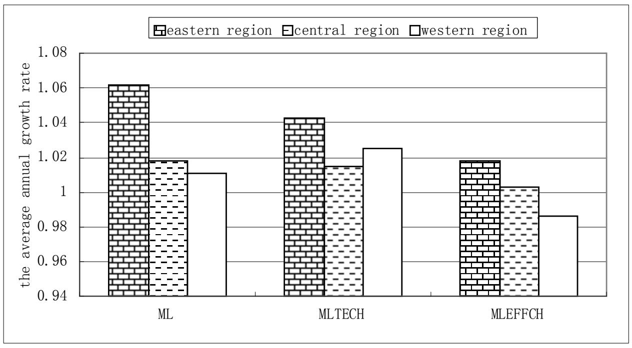

Fig. 1: Agricultural TFP of three regions when taking account of non-point source pollution.

$$P^t(x^t) = \left\{ \begin{array}{ll} (y^t, u^t : \sum_{k=1}^{K} z_k^t x_{kn}^t \le x_n^t, & n = 1,2,\cdots,N; \\ \sum_{k=1}^{K} z_k^t y_{km}^t \ge y_m^t, & m = 1,2,\cdots,M; \\ \sum_{k=1}^{K} z_k^t u_{ki}^t = u_i^t, & i = 1,2,\cdots,I \\ z_k^t \ge 0, & k = 1,2,\cdots,K \end{array} \right\} \quad ...(1)$$

Where, z_k^t is the weight of production unit k (k = 1,2,...,K). All is non-negative and to the sum is 1, meaning the scale return of environmental technology is variable. If we remove the constraint of sum with 1, it means that the scale return is constant.

The traditional TFP estimates are based on Shephard distance function, in which it is required that "good output" and "bad output" are increasing with the same proportion, but this does not meet the requirements of productivity evaluation. The directional distance function can measure the agricultural TFP under environmental constraints, because the decreasing possibility of "bad output" as the same proportion with increasing of "good output" can be considered at the same time. Let the direction vector of output be $g = (g_y, g_u)$, then the directional distance function based on the output can be expressed as follow:

$$\overrightarrow{D_0^t}(x^t, y^t, u^t; g_y, -g_u) = \sup[\beta : (y^t + \beta g_y, u^t - \beta g_u) \in p^t(x^t)] \quad ...(2)$$

Where β represents the maximum multiples of "good

Table 1: Elementary unit of agricultural non-point source pollution.

Pollution source	Survey unit	Survey index
Fertilizer	Nitrogen fertilizer, phosphate fertilizer, compound fertilizer	Applying quantity of chemical fertilizer
Agricultural solid wastes	Rice, wheat, corn, soybean,potato, rapeseed	The total output
Livestock and poultry breeding	Cow, pig, sheep, chicken, duck	Sales amount
Aquaculture	Freshwater aquaculture	The total output

output" *y,* and "bad output" *u* increase or decrease as the same proportion brought by a certain input *x* and technical structure *P(x).* β can be solved by the following linear programming equation:

$$\text{s.t.}\begin{cases}\sum_{k=1}^{K} Z_k^t y_{ki}^t = (1-\beta)U_{k'i}^t, & i=1,2,\cdots,I \\ (1+\beta)y_{k,m}^t \le \sum_{k=1}^{K} Z_k^t y_{k'm}^t, & m=1,2,\cdots,M \\ \sum_{k=1}^{K} Z_k^t y_{kn}^t \le x_{k'n}^t, & n=1,2,\cdots,N \\ Z_K^t \ge 0, & k=1,2,\cdots,K \end{cases} \qquad ...(3)$$

Based on directional distance function, by introducing the dynamic concept of intertemporal, the total factor productivity (TFP) index under the constraints of resources and environment from *t* to *t*+1 can be defined as follows:

$$ML_t^{t+1} = \left[\frac{1+\overrightarrow{D_0^t}(x^t,y^t,u^t;y^t,-u^t)}{1+\overrightarrow{D_0^t}(x^{t+1},y^{t+1},u^{t+1};y^{t+1},-u^{t+1})} \times \frac{1+\overrightarrow{D_0^{t+1}}(x^t,y^t,u^t;y^t,-u^t)}{1+\overrightarrow{D_0^{t+1}}(x^{t+1},y^{t+1},u^{t+1};y^{t+1},-u^{t+1})}\right]^{1/2} \qquad ...(4)$$

ML indices can be further decomposed into efficiency improvement index (MLEFFCH) and technical progress index (MLTECH):

$$ML_t^{t+1} = MLEFFCH_t^{t+1} \times MLTECH_t^{t+1} \qquad ...(5)$$

$$MLEFFCH_t^{t+1} = \frac{1+\overrightarrow{D_0^t}(x^t,y^t,u^t;y^t,-u^t)}{1+\overrightarrow{D_0^{t+1}}(x^{t+1},y^{t+1},u^{t+1};y^{t+1},-u^{t+1})} \qquad ...(6)$$

$$MLTECH_t^{t+1} = \sqrt{\frac{1+\overrightarrow{D_0^{t+1}}(x^t,y^t,u^t;y^t,-u^t)}{1+\overrightarrow{D_0^t}(x^t,y^t,u^t;y^t,-u^t)} \times \frac{1+\overrightarrow{D_0^{t+1}}(x^{t+1},y^{t+1},u^{t+1};y^{t+1},-u^{t+1})}{1+\overrightarrow{D_0^t}(x^{t+1},y^{t+1},u^{t+1};y^{t+1},-u^{t+1})}}$$

Technical progress index measures the progress speed of advanced technology, which reflects the dynamic change of the outward expansion of production-possibilities frontier; efficiency improvement index measures the degree of actual production output approaching the maximum production output, which reflects the speed of the technology laggard catching up with the advanced. ML, MLTECH and MLEFFCH greater than (less than) 1 denote respectively the total factor productivity (TFP) growth (decline), technical progress (regress) and efficiency improvement (deterioration).

INDICATOR SELECTION

Input indicators: Labour, land, machinery, fertilizers and irrigation are selected as input indicators. The labour inputs are represented by the first industry practitioners, the land inputs are represented using the total sown area of crops, the agricultural machinery inputs are calculated by the total power of agricultural machinery, the amount of chemical fertilizers is calculated by the fertilizer volume for agricultural production multiplying by the active ingredient of fertilizer varieties including nitrogen, phosphorus and potash. The irrigation inputs are calculated by the real effective irrigation area.

Output indicators: "good" outputs of agriculture were calculated by the total output value of agriculture, forestry, animal husbandry and fishery valued by the constant prices in 1990. Agricultural "bad" outputs refer to emissions of agricultural non-point source pollution formed in the agricultural production and rural life activities. This investigation mainly accounts for the TN and TP which are two categories of agricultural non-point source pollution emissions poured into water. According to the development characteristics of rural economy in China, agricultural non-point source pollution mainly comes from fertilizer, livestock and poultry breeding, agricultural solid waste and rural life. On the basis of confirming the emission source of agricultural non-point source pollution, this investigation constructs the pollutant generation unit of the agricultural non-point source pollution, and calculates the "bad" outputs by unit investigation and evaluation method. Table 1 shows the main sources of agricultural pollution.

The calculation formula of agricultural pollutant emissions is given as follows:

$$E_j = \sum_i EU_i \rho_{ij}(1-\eta_i)C_{ij}(EU_{ij},S) = \sum_i PE_{ij}\rho_{ij}(1-\eta_i)C_{ij}(EU_{ij},S) \qquad ...(7)$$

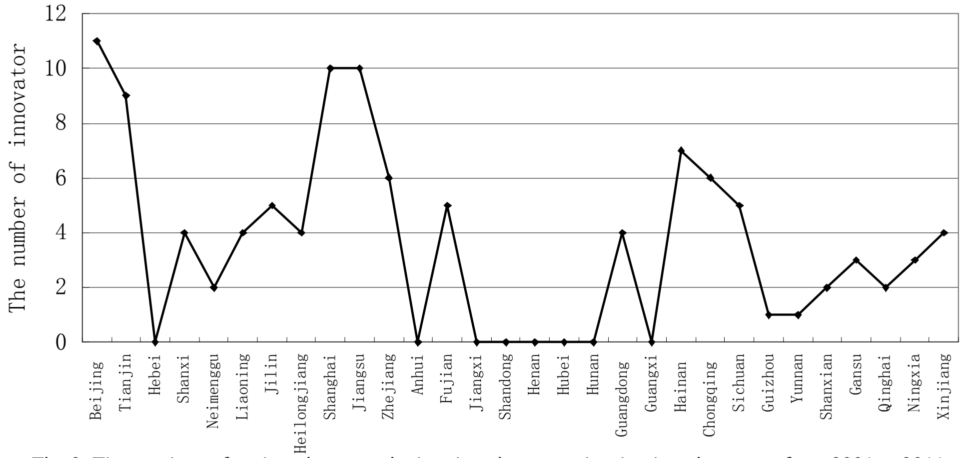

Fig. 2: The numbers of each region as agricultural environmental technology innovator from 2001 to 2011.

Where, E_j is the emission amount of agricultural pollutant j, EU_i is the statistical indicator number of unit i, ρ_{ij} is pollutant generation coefficient of unit i and pollutant j, η_t is the coefficient of relevant resource utilization efficiency, PE_{ij} represents the amount of pollutants j, C_{ij} is pollutant discharge coefficient of unit i and pollutant j, which is determined by the unit characteristics and spatial characteristics.

Data description: The data used in the empirical analysis are from 2000 to 2011 and the samples come from 30 regions in China. Tibet is not included in the analysis framework just because of the missing data. In terms of estimating the amount of pollutant emissions, all the statistics are from the official statistical Yearbook. Parameter values such as the pollutant generation and discharge coefficient are obtained through relevant references (Lai et al. 2004, Chen et al. 2006) and "Handbook for the Pollutant Generation and Discharge Coefficient of Pollution Source Investigation" which was issued by the leading group office of pollution source general survey in China.

EMPIRICAL ANALYSIS

According to the above analysis, we calculate and decompose the agricultural TFP of various regions in China.

Changes of agricultural TFP: Table 2 gives the average agricultural TFP of various regions in China from 2000 to 2011. As can be seen, whether considering agricultural non-point source pollution or not, since 2000, agricultural TFP growth is obvious. Without considering the environmental pollution, average annual growth of agricultural TFP is 5.4 %, in which the technical progress has an average annual growth rate with 6.4 %, while technical efficiency has a regression growth with an average annual growth rate of 0.009 %. The largest agricultural TFP annual growth rate occurred in 2009 with 6.5 %. When considering agricultural non-point source pollution, the annual growth rate of agricultural TFP is 3.8 %, of which the average annual growth rate of technical progress is 3.4 %, and the average annual growth rate of technical efficiency is only 0.4 %. The largest agricultural TFP annual growth rate is 5.9 % in 2011.

The average annual growth rate of agricultural TFP when considering the environmental pollution (3.8 %) is significantly lower than that without considering environmental contamination (5.4 %). It indicates that the growth rate of "good" output is lower than the reduction rate of "bad" output in the agricultural development of China, meanwhile along with extensive growth which is obtained at the expense of seriously damaging the ecological environment and consuming a lot of resources.

Analysis of regional differences: Fig. 1 shows agricultural TFP of three regions (eastern, central, western in China) when taking account of non-point source pollution. As we can see, from the east to the west, the average annual growth rate of agricultural TFP decreases gradually. The agricultural TFP annual growth rate of eastern region is 6.2 %, which is much higher than the central region (1.8 %) and western region (1.1 %). With regard to the agricultural technology progress, the average annual growth rate of central region is the lowest with only 1.5% among different regions. From the east to the west, the average annual growth rate of agricultural technical efficiency decreases gradually too. The above analysis indicates that the central and western regions demonstrate the "double- deterioration" situation of slow development of agricultural economic and environmental pollution. Thus, central and western regions of China should accelerate the transformation of agricultural development pattern in order to promote sustainable development of agriculture.

Analysis of Provincial differences: 1. Whether considering non-point source pollution or not, provincial differences of

Table 2: Growth and decomposition of agricultural TFP.

Year	Take account of non-point source pollution			Take no account of non-point source pollution		
	ML	MLTECH	MLEFFCH	M	TECH	EFFCH
2000-2001	1.015	1.040	0.976	1.041	1.082	0.962
2001-2002	1.019	1.028	0.991	1.046	1.096	0.954
2002-2003	1.021	1.017	1.004	1.043	1.042	1.001
2003-2004	1.029	1.021	1.008	1.052	1.048	1.004
2004-2005	1.031	1.020	1.011	1.053	1.079	0.976
2005-2006	1.036	1.019	1.017	1.061	1.080	0.982
2006-2007	1.044	1.052	0.992	1.064	1.070	0.994
2007-2008	1.051	1.044	1.007	1.062	1.053	1.009
2008-2009	1.056	1.043	1.012	1.065	1.050	1.014
2009-2010	1.056	1.047	1.009	1.058	1.044	1.013

Table 3: Agricultural TFP in each region from 2000 to 2011.

Region	Take no account of non-point source pollution	Take account of non-point source pollution	Region	Take no account of non-point source pollution	Take account of non-point source pollution
Beijing	1.154	1.122	Henan	1.043	1.021
Tianjin	1.051	1.046	Hubei	1.042	1.034
Hebei	1.052	1.048	Hunan	1.046	1.032
Shanxi	1.033	1.029	Guangdong	1.062	1.051
Neimenggu	1.019	1.013	Guangxi	1.038	1.022
Liaoning	1.058	1.039	Hainan	1.074	1.061
Jilin	1.051	1.046	Chongqing	1.042	1.041
Heilongjiang	1.053	1.045	Sichuan	1.0388	1.032
Shanghai	1.086	1.115	Guizhou	1.024	1.021
Jiangsu	1.049	1.052	Yunnan	1.021	1.012
Zhejiang	1.116	1.075	Shanxian	1.031	1.019
Anhui	1.041	1.032	Gansu	1.028	1.021
Fujian	1.062	1.048	Qinghai	1.037	1.017
Jiangxi	1.043	1.037	Ningxia	1.042	1.023
Shandong	1.054	1.026	Xinjiang	1.043	1.028

agricultural TFP are large. For example, when considering the non-point source pollution, average annual growth rate of agriculture TFP in Beijing is 12.2 %, while Yunnan is only 1.2 %. 2. Without considering non-point source pollution, the top five regions regarding the average annual growth rate of agricultural TFP are as follows: Beijing (15.4 %), Zhejiang (11.6 %), Shanghai (8.6 %), Hainan (7.4 %), Fujian (6.2 %). The last five regions regarding the average annual growth rate of agricultural TFP are as follows: Neimenggu (1.9 %), Yunnan (2.1 %), Guizhou (2.4 %), Gansu (2.8 %), Shanxian (3.1 %). When considering non-point source pollution, the rankings change little. 3. When considering non-point source pollution, agricultural TFP annual growth rate declines in most regions; only Shanghai and Jiangsu appears to rise. It means that with the growth of agricultural TFP, non-point source pollution reduces gradually in the two regions, and eventually achieves the win-win situation of 'development and environment'.

Identification of environmental technology innovator: This investigation attempts to find out the technology innovator of agricultural environment, namely, which provinces are exactly dominating the moving of the production-possibility frontier per year. According to the research of Fare et al. (2001) and Kumar (2006), the paper introduces the following model:

$$\begin{cases} MLTECH_t^{t+1} \succ 1 \\ \overrightarrow{D_0^t}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}) \prec 0 \\ \overrightarrow{D_0^{t+1}}(x^{t+1}, y^{t+1}, b^{t+1}; y^{t+1}, -b^{t+1}) = 0 \end{cases} \quad ...(8)$$

In the above model, the first condition means that from stage to stage, the production-possibility frontier is an outward expansion. The second condition means that the value of input-output in stage cannot be achieved with the environment technology structure in stage, i.e., after the occurrence of technological advances, the production in stage is out of the scope of production-possibility frontier at stage. The third condition means that the "environmental technology innovator" must fall in the scope of production-possibility frontier at current stage. If all these three conditions are met at the same time, the production unit is the "environmental technology innovator".

As can be seen in Fig. 2, from 2001 to 2011, a total of 22 regions have promoted the movement of production-possibility frontier at least once during the period. In which, the number of times of Beijing as the technology innovator are the most high, up to 11 times, followed by Shanghai and Jiangsu which have 10 times. As per to Hebei, Anhui, Jiangxi, Shandong, Henan, Hubei, Hunan and Guangxi provinces, all have never been the technology innovator agricultural environment for even one time. These results further illustrate that when considering environmental pollution, some regions, such as Anhui, Shandong, Henan and Hunan province, mainly rely on investment, not technological progress and technical efficiency although their agricultural productions are high.

CONCLUSIONS

If we do not consider environmental pollution, it may produce incorrect results of the agricultural TFP which will lead to the incorrect policies and regulations formulated by the government. In order to remedy this defect, this paper took the agricultural non-point source pollution into the analysis framework of agricultural TFP, using Malmquist-Luenberger productivity index to re-measure the agricultural TFP of various regions in China from 2001 to 2011. The results were shown as follows: Firstly, in the past 11 years, the agricultural TFP of China has increased rapidly, and technological progress was the major contributor, rather than the technical efficiency. Secondly, the average annual growth rate of agricultural TFP when considering the environmental pollution, was significantly lower than the value without considering environmental contamination. It indicated that environmental pollution had caused a greater loss of agricultural development efficiency in China. Agricultural economic growth of China was the extensive growth obtained at the expense of seriously damaging the ecological environment and consuming a lot of natural resources. Thirdly, similar to regional economic development pattern of China, the agricultural TFP of the eastern region was significantly higher than that of the middle and western regions. Lastly, the difference of agricultural TFP among different provinces in China was significant. The growth of agriculture in traditional agricultural provinces such as Henan, Hubei, Hunan, Anhui and the remote western provinces, was mainly dependent on putting in amount of natural resources, which resulted in the progressive deterioration of agricultural production environment.

The results indicated that for a long time, the rapid growth of China's agriculture was mainly dependent on the significant resources input of labour, land, pesticides, fertilizers and others. This traditional growth mode was realized by sacrificing the environment for agricultural development, which was difficult to achieve sustainable development. The government should further strengthen the research on modern agricultural technology such as environment-friendly agricultural production technology and cleaner production technology or low toxicity, low residue pesticides production and application technology. In addition, the government should formulate relevant policies and measures to promote the application of environment-friendly production technology over the whole country. Especially for the central and western regions, whose agricultural TFP was lower, they should strengthen exchanges and cooperation with the eastern regions through the introduction of advanced environment-friendly production technology and management experience in agriculture, gradually narrow the gap with the eastern region, and ultimately realize the coordinated development of agriculture and environment.

ACKNOWLEDGEMENTS

This research was supported by the Scientific and Technological Research Program of Chongqing Municipal Education Commission (KJ1401014).

REFERENCES

Chen Minpeng, Chen Jining and Lai Siyun 2006. Inventory analysis and spatial distribution of Chinese agricultural and mural pollution. China Environmental Science, 26(6): 751-755.

Fan, S. 1991. Effects of technological change and institutional reform on production growth in Chinese agriculture. American Journal of Agricultural Economics, 73(2): 266-275.

Fare, R., Grosskopf, S. and Margaritis, D. 2001. APEC and the Asian economic crisis: Early signals from productivity trends. Asian Economic Journal, 15(3): 325-341.

Fan Shenggen and Pardey, P.G. 1997. Research, productivity and output growth in Chinese agriculture. Journal of Development Economics, 53(1): 115-137.

Guo Junhua and Li, Bangyi 2009. The Calculation and convergence analysis of regional agricultural total factor productivity. Systems Engineering, 27(12): 31-37.

Johnson, D. G. and Richard, T. 1997. Ely lecture: Agriculture and the wealth of nations. American Economic Review, 87(2): 1-12.

Jiansheng Zhang, Kopytov, C. and Mou Qifang 2014. Study on the change and regional differences about total factor productivity considering the environmental pollution in China. Nature Environment and Pollution Technology, 13(2): 327-332.

Jin Huaiyu and Jian Lirong 2013. Calculation and analysis of agricultural TFP in China. Journal of Northwest A&F University (Social Science Edition), 13(2): 29-37.

Kumar, S. 2006. Environmentally sensitive productivity growth: A global analysis using Malmquist-Luenberger Index. Ecological Economics, 56(2): 280-293.

Lai Siyun, Du Pengfei and Chen Jining 2004. Evaluation of non-point source pollution based on unit analysis. Journal of Tsinghua University: Science and Technology Edition, 44(9): 1184-1187.

Qiao Zhen, Jiao Fangyi and Li Nan 2006. Change of rural institution and agricultural economic growth: An empirical analysis on agricultural economic growth in China. Economic Research, 7: 73-82.

Scott Rozelle and Huang Jikun 2005. China's rural economy and the path to a modern industrial state. China Economic Quarterly, 4(4): 1019-1042.

Wang, Yu, Song Wenfei and Han Xianfeng 2010. Research on agricultural TFP and its determinants in China. Chinese Rural Economy, 8: 24-35.

Wang Bing, Wu Yanrui and Yan Pengfei 2008. Environmental regulation and total factor productivity growth: An empirical study of the APEC economics. Economic Research, 5: 19-32.

Xi Liqing and Peng Kemao 2010. Analysis between rural economic institution change and agricultural periodic growth. China Population, Resources and Environment, 20(4): 123-129.

Zhang Jie, Ma Zhenzhen and Wu, Dengming 2014. Research on pollution characteristics of rural runoff. INMATEH - Agricultural Engineering, 42(1): 115-122.

Zhang Haibo and Liu Ying 2012. Growth and convergence of agricultural TFP in China. Statistics and Decision, (13): 139-142.

Zhang Yanhua and Liu Li 2006. Empirical analysis on contribution of rural human capital to rural economic growth. Journal of Central University of Finance & Economics, 8: 61-65.

Zhang B. and Carter C.A. 1997. Reforms, the weather and productivity growth in China's grain sector. American Journal of Agricultural Economics, 79(4): 1266-1277.