Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 16 | No. 2 | pp. 515-521 | 2017

Original Research Paper | Open Access

Evaluation of Agricultural Ecological Efficiency and its Improvement Measures in China Taking Guizhou Province as an Example

Wei Wang† and Yajun Ye
College of History and Ethnic Culture , Guizhou University, Guiyang, Guizhou 550025, China
†Corresponding author: Wei Wang

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 18-02-2017
Accepted: 25-04-2017

Key Words:
Agricultural ecological efficiency
Improvement measures
Guizhou province

ABSTRACT

The rapid development of the agricultural industry has led to the excessive waste of agricultural resources and the serious destruction of the ecological environment. Agriculture is the basis of national livelihood and economic development, and agricultural ecological efficiency is an important indicator of a region's agricultural productivity. Guizhou province of China is used as an example in this study to analyse the environmental pollution caused by the agricultural development process, quantitatively determine the agricultural ecological efficiency of a region, and propose measures to improve agricultural ecological efficiency. This study summarizes the development status of natural resources, environmental pollution etc. of agro-ecosystem in Guizhou province, and establishes the agricultural ecological efficiency evaluation indicator system. The agricultural ecosystem panel data of Guizhou province from 2005 to 2015 are also obtained. The data envelopment analysis-Malmquist model is used to calculate the agricultural ecological efficiency of Guizhou province from two levels, i.e., year and city, and the improvement measures for agricultural ecological efficiency are proposed. Results show that the agricultural ecological efficiency of Guizhou province is in the medium development level and increases by 7% on average. Technological progress is the most important factor of the growth of agricultural ecological efficiency. However, comprehensive technical efficiency decrease, and the decrease in scale efficiency are the main factors that cause the reduction in comprehensive efficiency level. The total factor productivity of all the cities in Guizhou province is greater than 1; among the cities, Liupanshui City reaches the highest growth rate, i.e., 12%. The results of this study possess a positive reference value for the adjustment of the agricultural ecosystem structure and the improvement of the agricultural ecological environment level. The findings may also serve as a basis for the enhancement of the comprehensive agricultural sustainable development and the alleviation of the serious destruction of the ecological environment caused by the rapid development of the agricultural industry.

INTRODUCTION

With the rapid global economic progress, the human society, the resources, and the environment also rapidly develops, albeit followed by a series of problems. Thus, people have become concerned about resource utilization and economic development. The contradiction between the growing material demand of mankind and the rarity of natural resources has become more intense. For this reason, mankind has become interested in investigating the internal relationship between resource utilization and economic development. Agricultural ecological efficiency has also become the focus of attention in many countries, with scholars analysing different methods to improve agricultural ecological efficiency. The ecological efficiency problem is based on the concept of eco-economics, i.e., how to use the limited resources to obtain the maximum output, emphasizing on the sustainability and permanency of resources. China needs to accelerate the pace of the development of modern agriculture and the improvement of comprehensive agricultural production capacity to ensure food supply security. At present, China is at a key stage of economic restructure. The country's overall economy is entering a new normal state, and its policies on resource recycling are obtaining strong support from the local governments. Moreover, China is gradually improving in its coordination among populations, resources, environment, and the society.

In fact, China's agricultural industry has been rapidly developing and its output has also been significantly improving. The diversification and commercialization of agriculture has provided outstanding contributions to China's rapid economic development and laid the foundation for the development of China's agricultural industry. However, the long-term unreasonable and nonstandard management of agriculture, seriously threatened China's agricultural ecological environment. Moreover, the generalization

and deepening of pollution problems significantly limited the long-term healthy development of China's agricultural industry. Burning of agricultural film causes a large amount of harmful substances to enter the atmosphere and considerably affect the air quality. The sustainable development of the agricultural ecosystem must maintain the comprehensive balance of the environment, resources, and economy; accelerate the development of the recycling efficiency of modern agriculture; reduce the agricultural input of chemical fertilizers; and address the problem of agricultural pollution. Therefore, hastening the analysis of the ecological efficiency of modern agriculture and constructing a reasonable ecological efficiency index system are important. Developing a qualitative and quantitative study of a specific agricultural ecosystem using a reasonable objective evaluation method is also a worthwhile pursuit. This study analyses the influencing factors of agricultural ecological efficiency in all directions and perspectives. This goal is achieved by establishing a regional agro-ecosystem indicator system; conducting a case study on Guizhou province, China; and investigating the mechanisms of agricultural ecological efficiency influencing factors on agricultural sustainable development. Data envelopment analysis (DEA) evaluates the agricultural ecological efficiency of prefecture-level cities in Guizhou province. Such analysis compares the ecological efficiency differences among prefecture-level cities and proposes the corresponding policies to help improve the sustainable development level of China's agricultural ecosystem.

EARLIER STUDIES

At present, studies on the agricultural ecosystem mainly focus on qualitative and quantitative research methods. Moreover, the theoretical viewpoints of scholars differ. Indicator construction has not yet reached a unified consensus, and quantitative research is mainly concentrated on the field of farmer self-operation. Research on the evaluation of agricultural ecological efficiency has become the forefront of agricultural ecology analysis in the world. Moreover, the most research directions are focused on evaluating the health of the agricultural ecosystem, the influencing factors of the sustainable development of the agricultural ecosystem, and the scientific management of the agricultural ecosystem. In the context of the concept and function of agricultural ecosystems, Pimentel argued that a good agricultural ecosystem must have a high level of system integrity and sustainable development. The author also proposed that the best agricultural ecological development model for regional agricultural ecological development must be determined through the analysis of mode status (Pimentel 1992). Finkler presumed that agricultural ecosystems mainly include soil nutrient maintenance, biological management, nutrient cycling, waste assimilation, CO_2 uptake, and gene information retention. Through quantitative analysis, the author found that the sizes of agricultural ecosystem services are mainly affected by the intensity of agricultural production (Finkler et al. 1993). Halberg analysed and statistically processed the phosphorus and nitrogen contents in a Danish area. The other aspects of the study included the unit energy consumption of agricultural ecological products, agricultural production environment, water resources irrigation rate, weed occupancy rate, and pest management situation (Halberg et al. 1995). Shenaifi and other researchers constructed a sustainable development evaluation index system for different ecological farms in France. This system was based on ecological energy balance. The scholars then observed an effective energy utilization efficiency value higher than that of previous years (Shenaifi 2013). Maia argued that improvements in agricultural eco-efficiency can improve water use efficiency, reduce water and energy consumption, and reduce the pollution caused by fertilizer use (Maia et al. 2016). Georgopoulou analysed the methods used to improve agricultural ecological efficiency by improving the ecological benefits of the use of agricultural water systems (Georgopoulou et al. 2016). Hochman described the present situation of agricultural production in Australia by using the DEA method to calculate the agricultural production efficiency in the region. Such efficiency was calculated in terms of the measurement of the agricultural ecological efficiency and the improvement of agricultural ecology and other aspects (Hochman et al. 2013). Cerutti evaluated the overall ecological efficiency of the fruit production system in northern Italy (Cerutti et al. 2013). Falavigna analysed the interaction among the environmental efficiency, the productivity, and the public fund of the Italian agricultural industry (Falavigna et al. 2013). Keating presented the conceptual basis and framework for the analysis of agricultural ecological efficiency (Keating et al. 2013). Thanawong analysed the ecological efficiency of rice production in northeastern Thailand (Thanawong et al. 2014). Pang used the data of 31 provinces in China from 2003 to 2013 to analyse the development level and spatial pattern of agricultural ecological benefits in China (Pang et al. 2016). Lin used the DEA method to analyse the agricultural ecology efficiency of Fujian province in China and proposed the corresponding improvement measures (Lin et al. 2016). Ullah used the DEA method to analyse the ecological environment performance of the cotton planting system in Pakistan (Ullah et al. 2016). Hengen analysed the overall ecological efficiency of farms in the US Great Plains (Hengen et al. 2016). Bonfiglio used the DEA method to calculate the ecological

efficiency of the Italian Marche region during the period of 2011 to 2014 and analysed the influence of economic, social, and political factors on agricultural ecological benefits (Bonfiglio et al. 2017). The induction and collation of the aforementioned literature revealed that many studies focused on the evaluation of the national and ecological regional efficiency. However, research on certain localities and poor areas, such as Guizhou, is inadequate and lacks empirical analysis. Moreover, the methods used in research to assess the ecological efficiency of the agricultural ecosystem tend to be qualitative. The literature focused on indicators and the studies that used quantitative methods are insufficient. The choice of indicators is also limited. The present study comprehensively analyses the current situation of agricultural mechanization development, agricultural production structure, and rural ecological efficiency of Guizhou province. The aim is to adjust the structure of the agro-ecosystem for various regions of Guizhou. This work adopts scientific management methods to improve the level of agricultural ecological environment.

MODEL INTRODUCTION AND DATA PROCESSING INSTRUCTIONS

DEA-Malmquist Model Introduction

The Malmquist index based on DEA is mainly used to determine the total factor productivity (TFP) and its analysis factors. According to Färe et al. (1994), the Malmquist index under the output-oriented variable returns to scale, with t and $t+1$ as the technical reference, can be defined as:

$$M_{t,t+1}=\frac{D_{t+1}^{v}\left(x_{t+1},y_{t+1}\right)}{D_{t}^{v}\left(x_{t},y_{t}\right)}\times\left[\frac{D_{t}^{v}\left(x_{t},y_{t}\right)}{D_{t}^{c}\left(x_{t},y_{t}\right)}\div\frac{D_{t+1}^{v}\left(x_{t+1},y_{t+1}\right)}{D_{t+1}^{c}\left(x_{t+1},y_{t+1}\right)}\right]\times$$
$$\left[\frac{D_{t}^{c}\left(x_{t},y_{t}\right)}{D_{t+1}^{c}\left(x_{t},y_{t}\right)}\times\frac{D_{t}^{c}\left(x_{t+1},y_{t+1}\right)}{D_{t+1}^{c}\left(x_{t+1},y_{t+1}\right)}\right]^{\frac{1}{2}} \quad ...(1)$$

In Formula (1), $D^{c}(x,y)$ is the distance function under the invariable returns to scale, whereas $D^{v}(x,y)$ is the distance function under the variable returns to scale. $\frac{D_{t+1}^{v}\left(x_{t+1},y_{t+1}\right)}{D_{t}^{v}\left(x_{t},y_{t}\right)}$ denotes the pure technical efficiency change, and $\frac{D_{t}^{v}(x_{t},y_{t})}{D_{t}^{c}(x_{t},y_{t})}\div\frac{D_{t+1}^{v}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}$ denotes the scale efficiency change. $\left[\frac{D_{t}^{c}(x_{t},y_{t})}{D_{t+1}^{c}(x_{t},y_{t})}\times\frac{D_{t}^{c}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}\right]^{\frac{1}{2}}$ signifies the technological progress, and $\frac{D_{t+1}^{v}\left(x_{t+1},y_{t+1}\right)}{D_{t}^{v}\left(x_{t},y_{t}\right)}\times\left[\frac{D_{t}^{v}(x_{t},y_{t})}{D_{t}^{c}(x_{t},y_{t})}\div\frac{D_{t+1}^{v}(x_{t+1},y_{t+1})}{D_{t+1}^{c}(x_{t+1},y_{t+1})}\right]$ represents the product of the first two terms and refers to the technical efficiency change.

When $M_{t,t+1}>1$, TFP increases and when $M_{t,t+1}<1$, TFP decreases. When $M_{t,t+1}=1$, TFP remains unchanged. If the technical efficiency change, pure technical efficiency change, scale efficiency change, or technical level change is greater than 1, then the corresponding change is the source of TFP growth. Otherwise, the change is the root of TFP reduction. In the study of agricultural ecological efficiency, TFP refers to the ratio of the total output to the weighted average of various input factors of agricultural ecology in production activities. Technological progress mainly refers to the growth of the production efficiency caused by the transmission and proliferation of scientific research, inventions, technological improvements, and high-tech enterprises in agricultural systems. Technical efficiency is mainly determined by two factors, namely, scale efficiency and pure technical efficiency. Scale efficiency means the deviation degree of the scales of the agricultural enterprises from the best scale in the production process. Pure technical efficiency mainly originates from agricultural enterprises. These enterprises improve and maximize the use of agricultural advanced equipment, management, talents, and other resources through enterprise system reform, agricultural technology innovation, and other management methods.

Data Sources

The agricultural ecosystem is a combination of nature and artificial work. Such ecosystem mainly includes water resources, land resources, human resources, mechanical resources, and auxiliary energy. Agricultural structure, resources, and other aspects are used to judge whether an agricultural ecosystem is efficient. The indicator system measuring the agricultural ecological efficiency must follow the principles of objectivity, scientific nature, integrity, and effectiveness. Many energy inputs and outputs in agricultural ecosystems are limited by natural resources and social economy. Domestic and foreign scholars have conducted many studies on ecological efficiency indicators. The most basic concept of agricultural ecological efficiency mainly considers the input and output indicators from the aspects of economy and environment during indicator selection. This study draws on the results of previous studies and constructs a new indicator system on the basis of the environment, resources, and economic development in accordance with the principles of science and objectivity along with the special geographical environment of Guizhou province and data availability. The indicator system is shown in Table 1.

This study covers the period from 2005 to 2015. This work involves nine prefecture-level administrative divisions of Guizhou province (including six prefecture-level cities and three autonomous prefectures). All of the data are based on the availability of agricultural-related statistics of Guizhou province and are obtained through the selection of relevant indicators of data from the Statistical Yearbook of Guizhou province (2006-2016) and the corresponding annual report of the relevant government agencies.

Table 1: Measurement and evaluation indicator system of agricultural ecological efficiency.

Indicator Type	First Class Indicators	Second Class Indicators	Unit
Input Indicators	Resource Index	Investment in Fixed Assets of Agriculture	100 000 000 Yuan (RMB)
		Proportion of Agriculture in Fiscal Expenditure	%Percentage
	Environmental Index	Fertilizer Pollution Load	Tons
		Pesticide Contamination Level	Tons
		Plastic Film Residual Quantity	Tons
Output Indicators	Economy Index	Agricultural Output Value	100 000 000 Yuan (RMB)

Table 2: Annual ecological efficiency values of Guizhou province.

	Technical Efficiency	Technical Progress	Pure Technical Efficiency	Scale Efficiency	Total Factor Productivity
2005-2006	1.02	0.91	1.00	1.02	0.93
2006-2007	0.97	1.17	1.00	0.97	1.14
2007-2008	1.00	1.13	1.00	1.00	1.14
2008-2009	0.99	1.05	1.00	0.99	1.03
2009-2010	0.97	1.19	1.00	0.97	1.16
2010-2011	0.98	1.11	1.00	0.98	1.09
2011-2012	1.01	1.02	1.00	1.01	1.03
2012-2013	0.98	1.07	1.00	0.98	1.04
2013-2014	0.99	1.08	1.00	0.99	1.07
2014-2015	0.96	1.06	1.00	0.94	1.08
Average Value	0.99	1.08	1.00	0.99	1.07

Table 3: Annual eco-efficiency values of Guizhou province.

	Technical Efficiency	Technical Progress	Pure Technical Efficiency	Scale Efficiency	Total Factor Productivity
Guiyang City	1.03	1.14	1.00	1.04	1.09
Liupanshui City	0.96	1.15	1.00	0.94	1.12
Zunyi City	1.01	1.04	1.00	1.02	1.11
Anshun City	0.96	1.05	1.00	0.94	1.03
Bijie City	0.94	1.19	1.00	0.96	1.16
Tongren City	0.98	1.11	1.00	1.04	1.09
Qiandongnan Prefecture	1.03	1.01	1.00	1.01	1.06
Qiandongnan Prefecture	0.98	1.05	1.00	0.99	1.04
Qiandongnan Prefecture	0.99	1.02	1.00	0.99	1.07
Average Value	0.99	1.08	1.00	0.99	1.09

EMPIRICAL RESEARCH

Annual Results Analysis

Using the DEAP 2.1 software, we perform a Malmquist index analysis of the panel data of nine prefecture-level administrative divisions of Guizhou province from 2005 to 2015. The analysis results of the Malmquist index are given in Table 2.

The analysis results given in Table 2 show that the agricultural ecological efficiency of Guizhou province increased by 7% on average during 2005 to 2015 and the overall development exhibited an increasing trend. Further analysis revealed that technological progress is the most important factor of the growth of agricultural ecological efficiency. This factor increased by 8% from 2005 to 2015. This finding shows that the improvement of the agricultural ecological efficiency of Guizhou province is mainly due to the growth of technological progress, which is consistent with the efforts and policies of China to promote agricultural production technology in recent years. Throughout the evaluation period, the Malmquist index of agricultural ecological efficiency reached the maximum value of 1.16 from 2009 to 2010, which benefited from China's efforts to promote the implementation of an environment-friendly

society and an agricultural green production policy. During this period, the government and farmers vigorously built farmland water conservancy facilities, and promoted agricultural technology, energy conservation, and emission reduction. The government and farmers also gave outstanding contributions to the green ecological development of agriculture. For most years, the comprehensive technology change index was less than 1, indicating that the integrated technical efficiency was declining. The trend of comprehensive technical efficiency is consistent with the variation trend of scale efficiency, which indicates that the decrease in scale efficiency is the main factor that causes the reduction in the comprehensive efficiency level. For most years, the index of scale efficiency is less than 1. This result indicates that the overall development of agriculture still lacks an effective planning and coordination mechanism, the common level within the agricultural industry is low, and the scale of the entire agricultural industry efficiency is difficult to achieve. From the point of view of technological progress, the index value of most years is greater than 1 and is consistent with the trend of the Malmquist index, which is the most important factor that promotes the growth of agricultural ecological efficiency. Therefore, in the process of agricultural production, the promotion of agricultural technological progress should be continuously increased. The level of agricultural ecological efficiency should also be promoted through the progress of production technology.

Analysis of Urban Results

Table 3 shows that during 2005 to 2015, the Malmquist index of all of the cities in Guizhou province is greater than 1. Among the cities, Liupanshui City achieved the highest growth rate, i.e., 12%, and its comprehensive technical efficiency and technological progress were relatively high. This finding indicates that the main factor of agricultural ecological efficiency growth is the technological progress of agricultural production. Other cities can learn from the specific practices of Liupanshui City to improve their levels of agricultural ecological efficiency by promoting agricultural production and technological progress.

MEASURES TO IMPROVE THE AGRICULTURAL ECOLOGICAL EFFICIENCY

Increase the Support for Agriculture and Attach Importance to Agricultural Development

Ecological agriculture is a new type of development industry in Guizhou province. However, ecological agriculture is a weekly developing industry. Such development is influenced by climate and market factors; hence, the support of the agricultural industry must be strengthened, and a diversified development strategy must be implemented during the development process. First, the policy of supporting agriculture and benefiting farmers of the local government must be strengthened and the support for the development and utilization of agricultural resources in the supporting process of the agricultural industry must be increased to improve the agricultural ecological efficiency of Guizhou province. Second, the government organizes each agricultural ecological garden to implement scientific management to increase the investment in agricultural ecological infrastructure and organizes and manages the management of the ecological garden to conduct timely learning to enrich basic knowledge of science. The assessment indicators of agricultural ecological efficiency must be increased to provide policy recommendations for agricultural ecological efficiency and to establish long-term and effective sustainable development mechanisms for agriculture. For the pollution of agricultural ecology, the government should play a leading role in the governance process, lead farmers to develop and use high-performance fertilizers and organic fertilizers, minimize pesticide residues, and strive to promote the use of plastic film with high standards and garbage collection.

Improve the Scientific and Technological Content of Agricultural Resource Utilization and Ensure the Sustainable Development of Agriculture

Science and technology are the primary productive forces. Since the reform and opening up of China, its scientific and technological level has been significantly improved. Moreover, science and technology has been increasingly used in the field of agricultural development. However, compared with western countries, China's agricultural science and technology still has some gaps, which should be overcome, and the overall agricultural science and technology capacity still has much room for improvement. In the future development of ecological agriculture, on one hand, importance should be attached to the support of science and technology to agricultural ecology, the introduction of foreign advanced agricultural science and technology talent should be increased, and the innovation ability of agricultural science and technology should be enhanced. Furthermore, economic incentives should be given to agricultural science and technology entrepreneurs. The utilization efficiency of agricultural ecological resources and product quality should be continuously improved, whereas the degree of environmental pollution in agricultural ecological construction should be reduced. Efficient food crops and healthy production techniques are taken as examples. On the other hand, the development of the transformation level of scientific and technological achievements should be accelerated, and

high technology should be applied to the construction of agricultural ecosystems in the shortest time.

Improve the Utilization Rate of Agricultural Resources and Increase the Efficiency Rate of Agriculture Comprehensive Utilization

An efficient and scientific method is adopted to improve the comprehensive productivity of agricultural ecological efficiency to ensure the long-term stability of agricultural ecosystems, and the utilization rate and utilization efficiency of agricultural ecological resources are gradually improved on the basis of the ensured development of the agricultural ecological environment of Guizhou province. To this end, the agricultural production space of autumn and winter must be vigorously developed, the reduction of unused rice fields in autumn and winter must be maximized, and land use must be improved. Then, the development of reserved land resources must be accelerated, and the cultivated area must be expanded. The use of chemical fertilizers, pesticides, and plastic films must be reduced, the quality of land resources must be continuously improved, and the output efficiency must be strengthened to improve the ecological efficiency of Guizhou province. Finally, the development of new resources must be accelerated, the cyclic utilization of crop straw and other resources must be increased, and the development efforts of solar energy, geothermal energy, water resources, and other clean resources must be improved through technological innovation. The cyclic utilization of agricultural waste resources must be considered, and the development of green agriculture must be increased.

Expand the New Functions of Agricultural Resources and Develop Modern Agriculture

Accelerating the development of new functions of agricultural ecological resources and the search for new agricultural resource applications is necessary to improve the agricultural ecological efficiency of Guizhou province further. First, the abundant autumn and winter unused land resources in Guizhou province must be used. Then, the development efficiency of idle land must be improved to alleviate the shortage of energy supply. Guizhou province is a large agricultural province with rich agricultural waste resources. In the follow-up development process, these resources can be effectively used to produce biogas, organic fertilizer, and other products. Guizhou province is a large province with abundant water resources. Hence, these resources can be used to develop hydropower stations to provide agricultural ecological construction with clean energy. Second, the development of tourism and leisure agriculture must be increased to achieve the maximum development of the leisure functions of agricultural resources, such as orchards and forest tourism.

CONCLUSION

China's agricultural and rural ecological environment problems have become increasingly prominent and seriously restrict the long-range development of agriculture because of long-term unreasonable and nonstandard agricultural management. Agricultural production has become an important source of environmental pollution in China. Excessive use of chemical fertilizers, pesticides, and agricultural films is the main reason for environmental pollution caused by agricultural production. The environmental pollution caused by the process of agricultural development must be analysed, the agricultural ecological efficiency of a region must be quantitatively determined, and the measures to improve the agricultural ecological efficiency must be proposed and implemented. This study takes Guizhou province as an example, establishes the evaluation indicator system of agricultural ecological efficiency, calculates the agricultural ecological efficiency of Guizhou province with the use of the DEA-Malmquist model measuring from the aspect of year and city, and proposes the improvement measures for the agricultural ecological efficiency. This study shows that the agricultural ecological efficiency of Guizhou province increases by 7% on average. Technological progress is the most important factor of the growth of agricultural ecological efficiency, but the decrease in scale efficiency leads to the decrease in comprehensive efficiency level. Agriculture pollution can be improved. Thus, agricultural ecological efficiency can be enhanced by further accelerating the sustainable development of modern agricultural ecosystem, maintaining the comprehensive balance of environment, resources, and economy, accelerating the development of the recycling efficiency of modern agriculture, and reducing the agricultural input of chemical fertilizers and other methods. This study mainly proposes the measures to improve the efficiency of the agricultural industry system by measuring the agricultural ecological efficiency of Guizhou province. Thus, future research can develop and conduct in-depth exploration by enriching the determination of the ecological efficiency evaluation index. Moreover, scientific and comprehensive ecological efficiency value methods should be considered, and the time series of research objects and other aspects expanded.

REFERENCES

Bonfiglio, A., Arzeni, A. and Bodini, A. 2017. Assessing eco-efficiency of arable farms in rural areas. Agricultural Systems, 151(2): 114-125.

Cerutti, A. K., Beccaro, G. L. and Bagliani, M. et al. 2013. Multifunctional ecological footprint analysis for assessing eco-efficiency: A case study of fruit production systems in Northern Italy. Journal of Cleaner Production, 40(3): 108-117.

Falavigna, G., Manello, A. and Pavone, S. 2013. Environmental efficiency, productivity and public funds: The case of the Italian agricultural industry. Agricultural Systems, 121(4): 73-80.

Färe R., Grosskopf S. and Norris M. 1994. Productivity growth, technical progress, and efficiency change in industrialized countries. American Economic Review, 84(5): 1040-1044.

Finkler, M.D. and Wirtschafter, D.D. 1993. Cost-effectiveness and data envelopment analysis. Health Care Management Review, 18(3): 81-88.

Georgopoulou, A., Angelis-Dimakis, A. and Arampatzis, G. et al. 2016. Improving the eco-efficiency of an agricultural water use system. Desalination and Water Treatment, 57(25): 11484-11493.

Halberg, N., Kristensen, E. S. and Kristensen, I.S. 1995. Nitrogen turnover on organic and conventional mixed farms. Journal of Agricultural and Environmental Ethics, 8(1): 30-51.

Hengen, T. J., Sieverding, H. L. and Cole, N.A. et al. 2016. Eco-efficiency model for evaluating feedlot rations in the Great Plains, United States. Journal of Environmental Quality, 45(4): 1234-1242.

Hochman, Z., Carberry, P. S. and Robertson, M.J. et al. 2013. Prospects for ecological intensification of Australian agriculture. European Journal of Agronomy, 44(2): 109-123.

Keating, B., Carberry, P. and Thomas, S. et al. 2013. Eco-efficient agriculture and climate change: Conceptual foundations and frameworks. International Center for Tropical Agriculture (CIAT), Cali, Colombia, 47(11): 19-28.

Lin, J., Fan, S. and Zheng, J. 2016. Comprehensive evaluation of agricultural eco-efficiency based on DEA model- a case study of Fujian province. DEStech Transactions on Social Science, Education and Human Science, 10(1): 12783.

Maia, R., Silva, C. and Costa, E. 2016. Eco-efficiency assessment in the agricultural sector: The Monte Novo irrigation perimeter, Portugal. Journal of Cleaner Production, 138(04): 217-228.

Pang, J., Chen, X. and Zhang, Z. et al. 2016. Measuring eco-efficiency of agriculture in China. Sustainability, 8(4): 398.

Pimentel, D. 1992. Farming in nature's image: An ecological approach to agriculture. BioScience, 42(9): 715-717.

Shenaifi, M.S. 2013. Attitudes of students at college of food and agricultural sciences toward agriculture. Journal of the Saudi Society of Agricultural Sciences, 12(2): 117-120.

Thanawong, K., Perret, S.R. and Basset-Mens, C. 2014. Eco-efficiency of paddy rice production in Northeastern Thailand: a comparison of rain-fed and irrigated cropping systems. Journal of Cleaner Production, 73(73): 204-217.

Ullah, A., Perret, S.R. and Gheewala, S.H. et al. 2016. Eco-efficiency of cotton-cropping systems in Pakistan: an integrated approach of life cycle assessment and data envelopment analysis. Journal of Cleaner Production, 134(10): 623-632.