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The driving forces of fertilizer use intensity by crops in China: A complete decomposition model

Dan Pan

Institute of Poyang Lake Eco-Economics, Jiangxi University of Finance and Economics, Nanchang 330013, China.

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Fertilizer plays an important role in raising agricultural production in China. However, the negative environmental consequences resulting from high fertilizer use intensity have posed serious challenges to agriculture sustainability in China. The goal of this study is to identify the underlying driving forces of fertilizer use intensity by crops that help to identify challenges and opportunities and provide advices for future policy measures. A complete decomposition method is employed to analyze the nature of the three factors that influence the changes in fertilizer use intensity by crops during the period of 2004 to 2011: fertilizer use efficiency effect, crop structure change effect and production efficiency effect. The results show that: (1) there were marked differences in the driving forces of fertilizer use intensity among different crops. The increase of fertilizer use intensity by grain crops was mostly affected by crop structure change and fertilizer use efficiency; the decline of fertilizer use intensity by economic crops was largely due to the crop structure change from high fertilizer use intensity type to low fertilizer use intensity type, while the increase of fertilizer use intensity by horticultural crops was mainly attributable to the crop structure change effect. The production efficiency had a positive effect on fertilizer use intensity decrease in all crops; (2) For the aggregate agricultural economy, the reduction of fertilizer use efficiency was the main factor in the growth of fertilizer use intensity, while the crop structure change and production efficiency change had minor effects on lowering fertilizer use intensity. We suggest that enhancing fertilizer use efficiency and changing crop structure should serve as essential approaches to reduce fertilizer use intensity in China.

Key words: Decomposition analysis, fertilizer use intensity, agriculture sustainability.

INTRODUCTION

The application of fertilizers is a major determinant in raising agricultural production and maintaining adequate food supplies in China (Wu, 2011). Despite a population of more than 1.3 billion which is about one-fifth of the world's total, China has been able to supply enough food for its growing population with about 7% of the world's arable land. A main contributor to such achievement is the increased use of chemical fertilizers (Zhong et al., 2007). According to the Food and Agriculture Organization (FAO), fertilizer globally contributes 40 to 60% of crop yield increase. In China, the figure was 57% during the period of 1978 to 2006 (Ma et al., 2014). Over the next two decades, due to the inadequate endowment and increased food security pressure, fertilizer will

E-mail:blesspanda@163.com; Tel: +86-18070062881; Fax: +86-791-8381-0892.

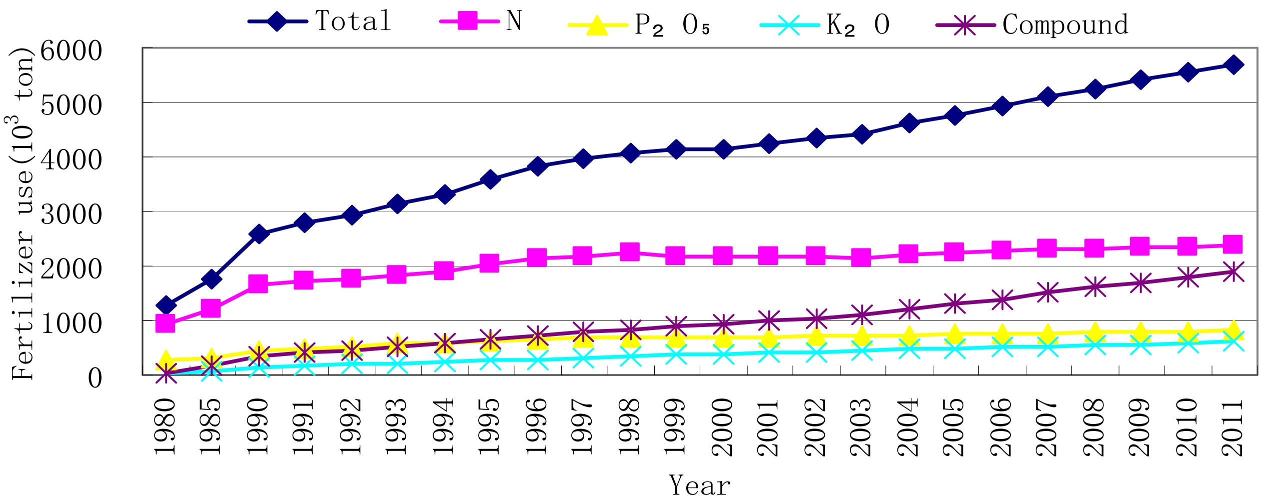

Figure 1. Fertilizer use amount in China from 1980 to 2011. Data Source: China Statistical Yearbook 2012.

Table 1. Fertilizer use rate during 1965-2009(unit: kg/ha).

Year / Country	1965	1970	1975	1980	1985	1990	1995	2000	2005	2006	2007	2008	2009
Netherlands	606	788	836	860	849	638	607	459	338	353	302	268	238
South Korea	156	262	420	390	417	490	549	455	643	470	511	480	362
Japan	338	376	364	373	419	386	354	325	348	333	350	278	291
China	25	44	70	158	143	221	287	279	408	434	479	463	504
Philippines	24	43	47	64	53	107	109	132	152	140	162	115	126
U.S.	64	82	101	114	95	100	113	105	119	126	123	106	109
India	5	14	21	34	53	74	86	103	128	136	143	153	167
World	37	53	70	88	94	100	94	100	115	120	127	119	122

Data Source: FAO, www.fao.org. Note: The fertilizer use here including nitrogenous fertilizer, phosphate fertilizer, potash fertilizer and compound fertilizer. These quantities are all measured in effective weight.

continue to make a key contribution to future agricultural development in China (Li et al., 2012).

The fertilizer use amount in China has grown rapidly in the late twentieth century, especially after the economic reform in the 1980s (Figure 1) (Gong et al., 2011). In addition, China's fertilizer use rate (kilograms per hectare, kg/ha hereafter) also has experienced a sustainable growth after 1960s and has surpassed the average level of the industrialized countries since 1980. From the late 1960s to 2009, fertilizer use rate in China has increased twenty times. By 2009, the fertilizer use rate in China has reached 504 kg/ha, which was 4 times greater than the global average (Table 1). Such high level of fertilizer use in China has raised concerns about its negative environmental consequences. For example, Zhu and Chen (2002), Ju et al. (2009) and Sun et al. (2012) showed that the high rate of fertilizer use has led to large N losses and has become the main source of water pollution and air pollution. A nation-wide pollution survey conducted by the Chinese Government identified that fertilizer was a major contributor to water-borne nitrogen, phosphorous pollution, and the increasing frequency of red tides (Zhang et al., 2013). Moreover, it is estimated that fertilizer production has accounted for 30% of agricultural greenhouse gas (GHG) emissions and was the source of about 8% of China's total GHG emissions (Liu and Zhang, 2011;Huang et al., 2012). Given the importance of fertilizer use with respect to GHG emissions and agriculture sustainability in China, a deeper understanding of the driving forces and their impacts on fertilizer use intensity is very important for the government to formulate fertilizer-reduction measures. Therefore, it is necessary to investigate the driving forces governing fertilizer use intensity.

Decomposition analysis is one of the widely employed tools for analysis of driving forces. In general, there are two kinds of decomposition techniques, one is the structural decomposition analysis (SDA) and the other is the index decomposition analysis (IDA) (Lei et al., 2012). SDA is based on input-output tables and is characterized by capable of more refined decomposition of economic and technological effects. IDA uses index number concept in decomposition. The advantage of IDA is that it has various indicator forms, mathematical (additive and multiplicative) specifications and indices, and can be readily applied to various available data at different levels of aggregation (Hoekstra and Van den Bergh, 2003). Considering the fertilizer use data in China, IDA is more applicable for our study.

Nowadays, a range of different index methods are available in the IDA group, such as Divisia index and Laspeyres index (Mahony, 2013). How to decompose the residual term has crucial influence on the accuracy and reliability of these methods. Sun (1998) introduced a complete decomposition model where the residual term is distributed among the considered effects. Zhang and Ang (2001) referred to this model as the refined Laspeyres method, which has been widely adopted due to its simplification of both calculation and understanding. Nowadays, the complete decomposition method has become popular in carbon emission, energy conservation, pollutant reduction, and so on (Zhang et al., 2009; Lise, 2006). However, to the best of our knowledge, the application of this technique to the analysis of fertilizer use intensity is still scarce.

In addition, most of the previous studies on China's fertilizer use intensity were conducted at the national level or regional level which is likely to capture an aggregate trend of fertilizer use intensity in China. However, it is important to note that few studies have been conducted to examine China's fertilizer use intensity from the point of crops and thus may be neglecting the influence of a significant crop structural shift that from grain crops to economic and horticultural crops occurred in China beginning in the 1990s (Li et al., 2007; Ma et al., 2012). So with the rapid transition of China's agricultural production structure, crop perspectives are important to understand the trends of fertilizer use intensity in China.

Therefore, in this study, we attempt to extend further the complete decomposition technique to fertilizer use intensity, and aim to identify, quantify and explain major driving forces acting to the changes of fertilizer use intensity by crops in China. By utilizing decomposition analysis, we can improve the foundation for fertilizer reduction policies as it reveals the contributions of different factors to the evolution of fertilizer use intensity.

MATERIALS AND METHODS

Complete decomposition method

Fertilizer use intensity is the ratio of fertilizer input to agricultural output in the production process. It is usually taken as a typical index to evaluate the efficiency of fertilizer use. Given that the substantial difference of fertilizer use intensity among grain crops, economic crops, and horticultural crops, driving forces of fertilizer use intensity will be analyzed with decomposition method from the point of crops. The related symbol definitions in the complete decomposition model are listed in Table 2. Following an extended Kaya identity, the fertilizer use intensity can be expressed as follows:

$$e_t = \frac{F_t}{Y_t} = \frac{\sum_i F_{it}}{\sum_i Y_{it}} = \sum_i (\frac{F_{it}}{Y_{it}})(\frac{Y_{it}}{Y_t}) = \sum_i (\frac{F_{it}}{Y_{it}})(\frac{y_{it}a_{it}}{y_t a_t}) = \sum_i (\frac{F_{it}}{Y_{it}})(\frac{y_{it}}{y_t})(\frac{a_{it}}{a_t}) = \sum_i e_{it} \cdot p_{it} \cdot s_{it}, i = 1,2,3 \quad (1)$$

Let e_t denote the fertilizer use intensity of a target year t and e_0 denote the fertilizer use intensity of base year 0, then

$$e_t = \sum_i e_{it} p_{it} s_{it}; e_0 = \sum_i e_{i0} p_{i0} s_{i0} \quad (2)$$

So the variation of fertilizer use intensity between a base year 0 and a target year t can be decomposed to three effects: (1) the fertilizer use efficiency effect which is caused by the variation of fertilizer use efficiency (denoted by e_{eff}) (2) the crop structure effect which is induced by the adjustment of crop sown area (denoted by e_{str});(3) the production efficiency effect which is caused by the changes in the production efficiency (denoted by e_{pff}) in additive form, as follows:

$$\Delta e = e_t - e_0 = e_{eff} + e_{str} + e_{pff} \quad (3)$$

According to the complete decomposition model given by Sun (1998), each effect in the right hand side of Equation (3) can be computed as follows:

$$e_{eff} = \sum_i s_{i0} p_{i0} \Delta e_i + \frac{1}{2} \sum_i \Delta e_i (p_{i0} \Delta s_i + s_{i0} \Delta p_i) + \frac{1}{3} \sum_i \Delta e_i \Delta s_i \Delta p_i \quad (4)$$

$$e_{str} = \sum_i e_{i0} p_{i0} \Delta s_i + \frac{1}{2} \sum_i \Delta s_i (p_{i0} \Delta e_i + e_{i0} \Delta p_i) + \frac{1}{3} \sum_i \Delta e_i \Delta s_i \Delta p_i \quad (5)$$

$$e_{pff} = \sum_i e_{i0} s_{i0} \Delta p_i + \frac{1}{2} \sum_i \Delta p_i (s_{i0} \Delta e_i + e_{i0} \Delta s_i) + \frac{1}{3} \sum_i \Delta e_i \Delta s_i \Delta p_i \quad (6)$$

In the index number, we form

$$\frac{e_{eff}}{\Delta e} \times 100\% + \frac{e_{str}}{\Delta e} \times 100\% + \frac{e_{pff}}{\Delta e} \times 100\% = 100\% \quad (7)$$

Or

$$\frac{e_t}{e_0} = 1 + \frac{e_{eff}}{e_0} + \frac{e_{str}}{e_0} + \frac{e_{pff}}{e_0} \quad (8)$$

Data

According to the methodology listed above, the data used in this paper includes agricultural output, sown area and fertilizer use amount by crops. Data of agricultural output and sown area by different crops were collected from China Statistical yearbook

Table 2. Summary of notations and definitions in the complete decomposition model.

Variables	Definition
F_t	Fertilizer use amount in year t
F_{it}	Fertilizer use amount of crop i in year t
Y_t	Agricultural output in year t
Y_{it}	Agricultural output of crop i in year t
a_t	Total sown area in year t
a_{it}	Sown area of crop i in year t
f_t	Fertilizer use amount per unit area in year t
f_{it}	Fertilizer use amount per unit area of crop i in year t
e_t , e_0	Fertilizer use intensity in year t and year 0, respectively
e_{it} , e_{i0}	Fertilizer use intensity of crop i in year t and year 0, respectively
s_{it} , s_{i0}	Sown area share of crop i in year t and year 0, respectively
p_{it} , p_{i0}	Production efficiency of crop i in year t and year 0, respectively

issued by the State Statistics Bureau. Data of fertilizer use amount was gathered from the compiled materials of costs and profits of agricultural products of China issued by the National Development and Reform Commission. This dataset contains detail information on the costs of all inputs and yields of China's major crops for a sample of more than 60,000 households (Wang, 2010). Through this dataset, we can have a better understanding of fertilizer use intensity by crops in China.

To make data suitable for the complete decomposition analysis by crops, we divide the agricultural economy of China into three sectors: the grain crops sector, the economic crops sector, and the horticultural crops sector. The grain crops include wheat, rice, maize (corn), and soybean. The economic crops are comprised of peanut, rapeseed, cotton, sugarcane, sugar-beet, and tobacco. The horticultural crops are subdivided into vegetable crops and fruit crops (Xin et al., 2012). This study covers the period from 2004 to 2011 for several reasons. First, the fertilizer use amount of horticultural crops is available after 2004. Second, since 2004, the Chinese Government has issued a number of measures to promote fertilizer market reforms and the fertilizer price has fluctuated substantially. How fertilizer use intensity has been changed under these backgrounds deserves attention. Third, just as Ebenstein et al. (2011) pointed out that the fertilizer use has a "lock-in" effect, which implies that the next year's fertilizer use intensity can be significantly predicted by prior application. So, taking the recent years from 2004 to 2011 for analysis will give better advices on future fertilizer-reduction measures.

RESULTS AND DISCUSSION

Analysis of fertilizer use intensity in China

Table 3 shows the trend of fertilizer use intensity in the period of 2004 to 2011. It can be seen that the average fertilizer use intensity of the aggregate agricultural economy, grain crops, economic crops, and horticultural crops during 2004 to 2011 period were 3,854.8 kiloton/billion tons (Kt/Bt hereafter), 5,829.4, 4,455.7 and 2,538.6 Kt/Bt, respectively. This result indicated that the grain crops had the highest fertilizer use intensity, followed by the economic crops, while the fertilizer use intensity of horticultural crops was the lowest. As is well established in the previous literatures, fertilizer use intensity between 1,420 to 2,500 Kt/Bt is the internationally accepted level (Cui et al., 2010; Mcallister et al., 2012). Thus, it can be concluded that China's fertilizer use intensity was much higher than the internationally accepted level. Appropriate measures should be taken to reduce such high fertilizer use intensity.

Table 3 also presents the growth rates of fertilizer use intensity from 2004 to 2011. It showed that the fertilizer use intensity of aggregate agricultural economy rose from 3,815.8 Kt/Bt in 2004 to 4,027.7 Kt/Bt in 2011, with a growth rate of 5.55%, or 211.9 Kt/Bt. The fertilizer use intensity of grain crops and horticultural crops increased significantly from 5,443.8 and 2,691.1 Kt/Bt in 2004 to 5,939.4 and 2,816.6 Kt/Bt in 2011, with a growth rate of 9.10 and 4.66%, respectively. The fertilizer use intensity of economic crops recorded a slight decrease from 4,589.9 Kt/Bt in 2004 to 4,542.6 Kt/Bt in 2011.

Driving forces of fertilizer use intensity by grain crops

As shown in Table 4, the fertilizer use efficiency and crop

Table 3. The growth rates of fertilizer use intensity from 2004 to 2011.

Year	Aggregate	Grain crops	Economic crops	Horticultural crops
2004	3,815.8	5,443.8	4,589.9	2,691.1
2005	3,745.8	5,725.4	4,695.2	2,377.8
2006	3,865.5	5,780.6	4,569.3	2,499.9
2007	3,920.6	6,033.3	4,433.2	2,497
2008	3,610.2	5,643.9	3,909.4	2,273.1
2009	3,792.4	5,905.3	4,332.1	2,418.8
2010	4,060.9	6,163.7	4,573.7	2,734.5
2011	4,027.7	5,939.4	4,542.6	2,816.6
Average	3,854.8	5,829.4	4,455.7	2,538.6
2004-2011(Kt/Bt)	211.9	495.6	-47.3	125.5
2004-2011(%)	5.55	9.10	-1.03	4.66

Table 4. Decomposition of fertilizer use intensity in grain crops.

Period	Δe (Kt/Bt)	e_{eff} (Kt/Bt)	e_{str} (Kt/Bt)	e_{pff} (Kt/Bt)	$e_{eff} / \Delta e$	$e_{str} / \Delta e$	$e_{pff} / \Delta e$
2004-2005	281.65	278.78	15.21	-12.34	98.98	5.40	-4.38
2005-2006	55.16	43.23	8.72	3.21	78.37	15.81	5.82
2006-2007	252.66	276.42	-8.33	-15.43	109.40	-3.30	-6.11
2007-2008	-389.34	-409.54	12.52	7.68	105.19	-3.22	-1.97
2008-2009	261.39	291.16	-14.31	-15.46	111.39	-5.47	-5.91
2009-2010	258.38	255.57	12.13	-9.32	98.91	4.69	-3.61
2010-2011	-224.27	-221.91	-13.32	10.96	98.95	5.94	-4.89
Average	**495.63**	**471.87**	**41.65**	**-17.89**	**95.21**	**8.40**	**-3.61**

structure contribution rates were positive values in the growth of grain crops' fertilizer use intensity during 2004 to 2011. The accumulated fertilizer use efficiency effect was an increase of 471.87 Kt/Bt, which accounted for 95.21% of the total change in absolute value. The results indicated that the fertilizer use efficiency effect played the dominant role in increasing fertilizer use intensity of grain crops. This reflects that the advancement of fertilizer use efficiency is effective for reducing fertilizer use intensity in the grain crops. The crop structure effect was another factor that increased fertilizer use intensity over the study period, but its contribution was tiny. The accumulated crop structure effect was an increase of 41.65 Kt/Bt, which only accounted for 8.40% of the total fertilizer use intensity change in absolute value. The change in the production efficiency effect played a very minor role in decreasing fertilizer use intensity. This effect decreased fertilizer use intensity in most years except 2006 which resulted in an accumulated decrease of 17.89 Kt/Bt and accounted for 3.61% of the total fertilizer use intensity change in absolute value.

Driving forces of fertilizer use intensity by economic crops

Table 5 illustrates that the crop structure change was the most important factor in the reduction of fertilizer use intensity in the economic crops. The accumulated crop structure effect was a decrease of -435.65 Kt/Bt which accounted for 922.29% of the total change. This result indicated that the structure of China's economic crops has been optimized and has shown "fertilizer-saving" reorientation. The production efficiency change also had a positive effect on fertilizer use intensity decrease, but its contribution was trivial which only accounted for 9.65% of the total fertilizer use intensity change in absolute value. The fertilizer use efficiency change had a negative effect on fertilizer use intensity decrease. During 2004 to 2011, the fertilizer utilization efficiency lead to an increase of 831.94% of the total change in fertilizer use intensity, which reflected that the improvement of fertilizer use efficiency was necessary for fertilizer use intensity decrease in the economic crops.

Driving forces of fertilizer use intensity by horticultural crops

The decomposition results of horticultural crops were given in Table 6. For horticultural crops, the biggest contributor to the high increase of fertilizer use intensity was crop structure change effect. During the period of 2004 to 2011, 137.43 Kt/Bt fertilizer use intensity increase

Table 5. Decomposition of fertilizer use intensity in economic crops.

Period	Δe (Kt/Bt)	e_{eff} (Kt/Bt)	e_{str} (Kt/Bt)	e_{pff} (Kt/Bt)	e_{eff} / Δe	e_{str} / Δe	e_{pff} / Δe
2004-2005	105.37	160.87	-45.63	-9.87	152.67	-43.30	-9.37
2005-2006	-125.91	-12.89	-121.34	8.32	10.24	96.37	-6.61
2006-2007	-136.14	97.20	-222.36	-10.98	-71.39	163.33	8.07
2007-2008	-523.75	-459.73	-98.67	34.65	87.78	18.84	-6.62
2008-2009	422.59	344.46	123.56	-45.43	81.51	29.24	-10.75
2009-2010	241.62	285.19	-57.89	14.32	118.03	-23.96	5.93
2010-2011	-31.02	-73.79	34.56	8.21	237.90	-111.43	-26.47
Average	**-47.24**	**392.97**	**-435.65**	**-4.56**	**-831.94**	**922.29**	**9.65**

Table 6. Decomposition of fertilizer use intensity in horticultural crops.

Period	Δe (Kt/Bt)	e_{eff} (Kt/Bt)	e_{str} (Kt/Bt)	e_{pff} (Kt/Bt)	e_{eff} / Δe	e_{str} / Δe	e_{pff} / Δe
2004-2005	-313.27	20.31	-343.45	9.87	-6.48	109.63	-3.15
2005-2006	122.12	-2.49	133.56	-8.95	-2.04	109.37	-7.33
2006-2007	-2.87	-1.20	-2.65	0.98	41.86	92.26	-34.12
2007-2008	-223.97	16.61	-251.23	10.65	-7.42	112.17	-4.76
2008-2009	145.72	-6.30	159.87	-7.85	-4.32	109.71	-5.39
2009-2010	315.73	-7.74	343.23	-19.76	-2.45	108.71	-6.26
2010-2011	82.12	-10.60	111.26	-18.54	-12.91	135.49	-22.58
Average	**125.58**	**-7.88**	**137.43**	**-3.97**	**-6.27**	**109.44**	**-3.16**

was attributable to crop structure change, which accounted for 109.44% of the total change in absolute value. This indicated that it is necessary to adjust crop structure from high fertilizer use intensity type to low fertilizer use intensity type to strengthen low fertilizer utilization in the horticultural crops. The fertilizer use efficiency change had a negative effect on fertilizer use intensity increase. The accumulated fertilizer use efficiency effect was a decrease of -7.88 Kt/Bt, which accounted for -6.27% of the total fertilizer use intensity change. According to the China's 12th five-year plan of agriculture and rural economic development (2011 to 2015), with the rapid development of industrialization, urbanization, agricultural modernization process and the transformation of food consumption structure in China, the planting area of horticultural crops will maintain a sustained and rapid growth. Therefore, improving fertilizer use efficiency should serve as an essential approach to the reduction of fertilizer use intensity in China. The production efficiency change also had a negative effect on fertilizer use intensity increase, but its contribution was trivial which only accounted for 3.16% of the total fertilizer use intensity change in absolute value.

Driving forces of fertilizer use intensity by the aggregate agricultural economy

The changes of fertilizer use intensity in the aggregate agricultural economy of China were shown in Table 7. The fertilizer use efficiency effect played a dominant role in the growth of fertilizer use intensity in China. During 2004 to 2011, the fertilizer utilization efficiency accounted for 114.99% of the total change in fertilizer use intensity. As we all known, the maintenance of maximum crop yields to safeguard high levels of food security has been a central objective of the Chinese Government for many decades. Under the situation of high yield production, the Chinese Government encouraged farmers to use more fertilizer to attain higher yields and support China's domestic food security (Good and Beatty, 2011). China's food security success could not have been achieved without fertilizer use since 1980 (Figure 2). However, there is unequivocal evidence that fertilizer use is much higher than what is required for high crop yields and 95% food grain self-sufficiency. Approximately one-third of the cropland suffers from fertilizer overuse (Ju et al., 2009). Thus, the high level of fertilizer use tends to result in low fertilizer use efficiency.

The crop structure change and the production efficiency change were all negative values in the growth of fertilizer use intensity which indicated that these two factors were effective in reducing fertilizer use intensity in the aggregate agricultural economy. The accumulated crop structure change effect and production efficiency change were a decrease of -21.45 and -10.32 Kt/Bt respectively, which accounted for -10.12 and -4.87% of

Table 7. Decomposition of fertilizer use intensity for all crops.

Period	Δe (Kt/Bt)	e_{eff} (Kt/Bt)	e_{str} (Kt/Bt)	e_{pff} (Kt/Bt)	$e_{eff} / \Delta e$	$e_{str} / \Delta e$	$e_{pff} / \Delta e$
2004-2005	-70.01	-70.29	-2.06	2.34	100.40	2.94	-3.34
2005-2006	119.72	81.81	45.67	-7.76	68.33	38.15	-6.48
2006-2007	55.07	71.73	-13.45	-3.21	130.25	-24.42	-5.83
2007-2008	-310.36	-332.81	6.78	15.67	107.23	-2.18	-5.05
2008-2009	182.20	214.10	-21.58	-10.32	117.51	-11.84	-5.66
2009-2010	268.51	316.70	-31.45	-16.74	117.95	-11.71	-6.23
2010-2011	-33.24	-31.98	-3.24	1.98	96.21	9.75	-5.96
Average	**211.91**	**243.68**	**-21.45**	**-10.32**	**114.99**	**-10.12**	**-4.87**

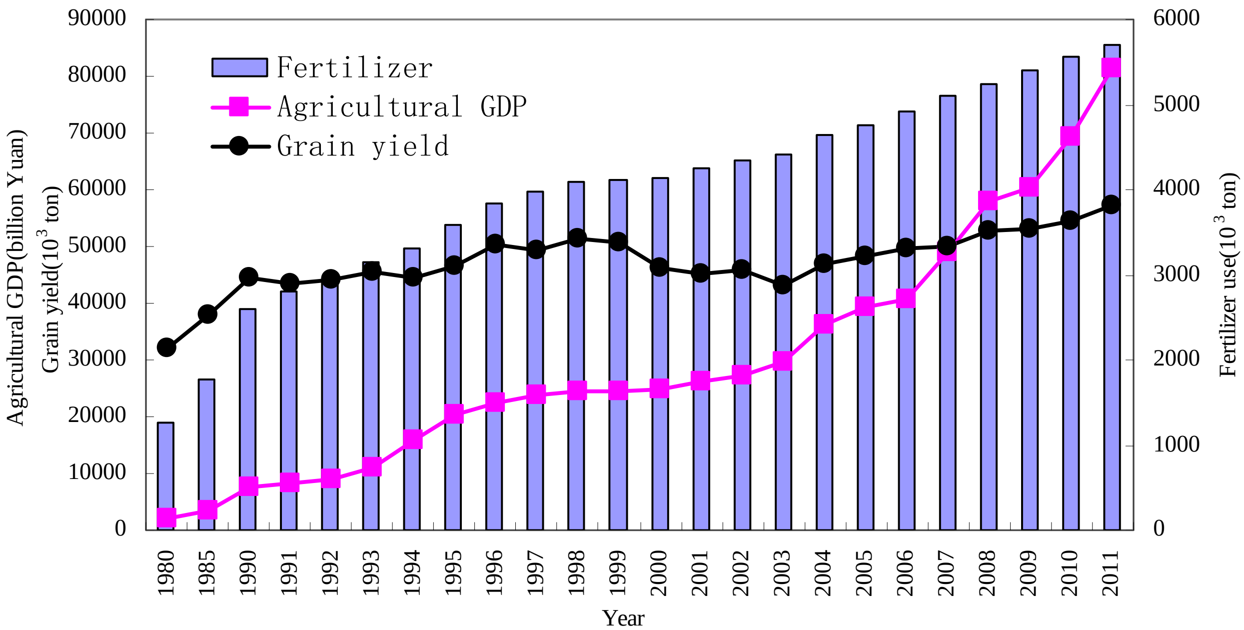

Figure 2. Agricultural GDP, grain yield and fertilizer use in China from 1980 to 2011.Data Source: China Statistical Yearbook 2012.

the total change, respectively.

Conclusion

In this paper, a complete decomposition method is used to study the underlying forces driving the fast-growing fertilizer use intensity in China during the period of 2004 to 2011. The factors that lead to changes in fertilizer use intensity are fertilizer use efficiency effect, crop structure change effect and production efficiency effect. We decompose the fertilizer use intensity from the crop level. This procedure sheds a better light on the driving forces influencing fertilizer use intensity and provides richer information that can be exploited for setting-up effective fertilizer use reduction countermeasures in each crop component. From this study, we may conclude: (1) Over the period of 2004 to 2011, the average fertilizer use intensity of the aggregate agricultural economy, grain crops, economic crops, and horticultural crops were all much higher than the internationally accepted level; (2) The fertilizer use intensity of grain crops increased 495.63 Kt/Bt during 2004 to 2011. The crop structure change and fertilizer use efficiency both had positive effects on the growth of fertilizer use intensity in grain crops, which increased 8.40 and 95.21% of the total fertilizer use intensity change, respectively. The production efficiency played a very minor role in decreasing fertilizer use intensity; (3) There was a slight decrease in the fertilizer use intensity of economic crops from 2004 to 2011, while this reduction was largely due to the crop structure change from high fertilizer use intensity type to low fertilizer use intensity type. The fertilizer use efficiency change had a negative effect on fertilizer use intensity decrease of economic crops; (4) The fertilizer use intensity of horticultural crops increased 125.58 Kt/Bt from 2004 to 2011, while this increase was mainly induced by the crop structure change. The fertilizer use efficiency change and production efficiency change had negative effects on fertilizer use intensity increase of horticultural crops; (5) The change of fertilizer use intensity of aggregate agricultural economy was a 211.91 Kt/Bt increase during 2004 to 2011. The reduction of fertilizer use efficiency was the main factor in the growth of fertilizer use intensity of aggregate agricultural economy, while the crop structure change and production efficiency change had minor effects on lowering fertilizer use intensity of aggregate agricultural economy.

China's 12th five-year plan (2011 to 2015) has stated reducing fertilizer use intensity as one of the agricultural development priorities. In order to achieve harmonized development of both agricultural economic growth and environmental sustainability, China must make great efforts to reduce its fertilizer use intensity. Based on our results, the following strategies should be undertaken to fertilizer use intensity reduction.

(1) Enhancing fertilizer use efficiency. The effective approaches for fertilizer use efficiency advancement should include: using modified forms of N fertilizer, especially inclusion of inhibitors to slow the release of N into crop-available forms and decrease gaseous losses. This requires adjustment of subsidies to cover the additional cost of incorporating inhibitors and as an incentive for farmers to adopt new techniques, promoting production of organic fertilizers from animal manure, employing integrated water and nutrient management and so on. Subsidies for initial cost of equipment and policies to ensure that training is provided by equipment or fertilizer suppliers are also needed. These measures can greatly increase the efficiency of fertilizer use.

(2) Adopting more effective methods of delivering information, both technical and economic to farmers, including Farmer Field Schools and working with Farmer Associations. These must take account of the current situations in which many farmers are involved in off-farm activities that impose a constraint on labour and make "best practice" for farm operations impracticable. Working through Farmer Professional Associations and using Farmer Field Schools are obvious ways forward. In some situations, the development of technicians or service providers from the private sector (or public-private partnerships) for delivering advice would be a positive development. These innovations require new policies and practices by government agencies that enable multiple approaches.

(3) Changing crop structure. Crop structure will continue to exert an important influence on China's fertilizer use. The adjustment of crop structure from high fertilizer use intensity type to low fertilizer use intensity type will lower fertilizer use intensity. This adjustment needs to be addressed through the removal of perverse subsidies for fertilizer production. Fertilizer subsidies once played an important role in developing China's fertilizer industry but are now an unacceptable and unnecessary distortion. It is now time to reallocate these economic resources to more positive measures such as the introduction of payments to farmers for environmental services.

The conclusions drawn from this study have an important reference value for policy makers in assisting their design and implementation of appropriate fertilizer reduction measures and also have academic value in terms of enriching low carbon agricultural economy research systems in China. However, this study is still preliminary. Only three effect factors are considered in this paper. If a method can study more effect factors, it will be useful to find how these influence the changes in fertilizer use intensity. Then, generalizing the complete decomposition model which can consider more effect factors could be the subject of another future research.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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