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An Ecological Research on Potential for Zero-growth of Chemical Fertilizer Use in Citrus Production in China

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Abstract

Overuse of chemical fertilizer has increased costs and damaged the agriculture ecological environment. Overuse of fertilizers in citrus (Citrus L.) orchards is becoming more serious in China. To understand the current status of farmer fertilization practice and the potential for fertilizer saving in citrus orchards in China would be meaningful for realizing the national policy of zero-growth in chemical fertilizer use. Therefore, the published literatures and statistical data were summarized to quantify the gap of citrus yield and fertilizer use efficiency among different countries, and to evaluate the potential for fertilizer saving in citrus production under different scenarios, and finally to suggest the strategies for both high yield and high efficiency of citrus production. The result showed that averaged citrus yield in China was 14.6 t/ha. Thus, the yield gaps, based on FAO data, were about 1.0 or 10 t/ha between China and the global averaged level or the average level of top 10 countries, respectively. On the other hand, the averaged rates of nitrogen (N), phosphorus (P) and potassium (K) fertilizer in orchards of major citrus producing regions of China were as high as 485,198 (P_2O_5), and 254 (K_2O) kg/ha, respectively. Thus, partial factor productivity from applied N (PFP_N) declined to 54.6 kg/kg in average which was only 30% of that in countries with advanced citrus industry such as USA, Brazil and South Africa. According to the domestic fertilization recommendation for citrus production in China, 62.0, 16.7 and 22.2 ten thousand tons will be saved for N, P and K fertilizer, respectively. This potential account 59.0%, 39.2% and 39.2% of estimated total amount of fertilizer used in citrus production in China. This fertilizer-saving potential can still work when the yield is projected to high yield level of 60 t/ha. In future, approaches including farmer training, moderate intensification, improvement of soil fertility, innovation of new-type fertilizers and methods for fertilizer application are needed to realize zero growth in chemical fertilizer use on citrus production in China or other similar countries.

Keywords: citrus, chemical fertilizer, nitrogen partial factor productivity, fertilizer-saving potential, ecological environment

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INTRODUCTION

China is the largest producer and consumer of chemical fertilizer around the world. The horticultural crops are becoming the major sources of increments of agricultural chemical fertilizer consumption in China due to their high intensification and production values, meanwhile the fertilizer use of cereal crops is relatively stable and even decreasing by the national extension of soil testing and formulated fertilization. Recent study reported that horticultural crops such as fruits and vegetables contributed 71.6% of the annual consumption increment of agricultural fertilizer in China (Xin *et al.* 2012). In aspect of the consumption structure of nitrogen (N) fertilizer, the proportion of N fertilizer used for fruit and vegetable crops is 39.0% in China (Wu 2014, Zhang *et al.* 2013), which is obviously higher than the global averaged proportion (15.3%) (Heffer 2009). China is the largest citrus (*Citrus* L.) producer with 31% of global cropping area and 25% of global citrus yield (FAO 2017), thus it plays an

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important role in regulating citrus production and international trade around the world. However, excessive fertilizer input during citrus production resulted in higher production costs, lower fertilizer utilization, heavier environmental pollution and other problems in China (Liu 2012). Therefore, estimating the fertilizer-saving potential and establishing integrated orchard nutrient management strategies including soil fertility improvement of citrus orchard and yield target are urgently needed for increasing citrus yield and quality, improving N use efficiency, reducing production costs and environmental pollution.

Previous farmer survey showed that most of citrus-grown farmers have not adjusted their fertilizing practices according to the soil fertility and citrus yield, resulting problems such as overuse N and phosphorus (P) fertilizers, imbalanced use of potassium (K) fertilizer, ignoring use of organic fertilizer and micronutrient fertilizers (Grassini *et al.* 2013). These farmers' practices therefore resulted directly or indirectly in lower citrus yield and quality, lower nutrient use efficiency, degraded soil fertility and quality, increased environmental pollution (Grassini *et al.* 2013). Studies have shown that the average yield of citrus in China is lower than that of the United States, Brazil and South Africa, but the amount of fertilizer input in China is 1~2 times higher than that in these countries (De Villiers and Joubert 2003, Mattos *et al.* 2012, Obreza and Morgan 2008). The early experience of those countries has shown that excessive application of N fertilizer cannot effectively increase citrus yield and even decrease the fruit quality. Studies in the United States, South Africa and Australia showed that the annual N rate of 150 kg ha^{-1} can maintain a high yield of citrus. The citrus yield is no longer increased when the N rate is more than 200 kg/ha (Dasberg 1987). These studies indicated that there is great potential for fertilizer-saving in citrus production in China. Therefore, quantifying and understanding the potential of fertilizer saving in citrus production in China is of great significance to implement the "Zero-growth action plan for fertilizer application by year of 2020" issued by the China's Ministry of Agriculture in 2015.

In this study, comparison of fertilizing practices, fertilizer use efficiency among major citrus-producing countries are conducted and the fertilizer-saving potential of citrus production in China is then quantified according to literature review, database statistics from FAO and the National Bureau of Statistics of China. To realize this potential, major limiting factors and related strategies for high citrus yield and high fertilizer efficiency in citrus production in China is further discussed. This study would be helpful to provide theoretical basis and technical support for realizing zero-growth of chemical fertilizer use and green increase of citrus production in China or similar countries.

MATERIALS AND METHODS

Data Source

Through "Web of Science" database (www.webofknowledge.com) and Chinese journal full-text database (www.cnki.net), 227 articles were retrieved by topics of "citrus or orange and fertilization and yield" and by the date range from 1985 to 2017. Fifty-three references with a total sample size of 1274 were further filtrated basing on standard that contains full details of yield, fertilizing information. There were 41 references with total sample size of 926 that came from nine provinces of major citrus planting area in China (www.moa.gov.cn). The data of citrus planting area was from the database of National Bureau of Statistics in China (http://data.stats.gov.cn). The data of citrus yield of major citrus-producing countries is originated from the FAO database (http://www.fao.org/faostat).

The data of the amount of fertilizer rate, orchard area, yield and organic matter in discussion section was from citrus orchard survey in Chongqing municipality, China in 2013. The sample size of survey questionnaire for fertilizing practice and planting area was 149, and the sample size of citrus yield and soil organic matter (SOM) was 459.

Data Analysis

The data including citrus yield, rate of N, P and potassium (K) fertilizer were extracted from previous filtrated literatures. And these data are used to calculate N use efficiency and fertilizer-saving potential at regional and national levels. According to the used parameters, partial factor productivity of N fertilizer (PFP_N) is used to evaluate N use efficiency. PFP_N refers to the ratio of crop yield to applied N fertilizer. The formula is shown below.

$$PFP_N(kg/kg) = Y/F_N \quad (1)$$

where Y is the citrus yield with the unit of kg/ha and F_N is the rate of N fertilizer input (kg/ha) in referred orchard.

Fertilizer-saving potential of citrus orchard (N, P_2O_5 or K_2O, kg/ha) is the difference between the fertilizer rate of farmers' practices (N, P_2O_5 or K_2O) and

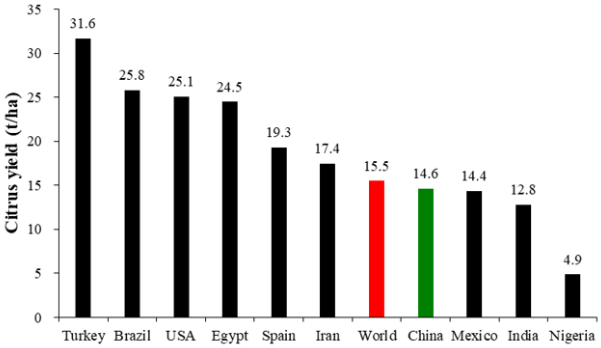

Fig. 1. Citrus yield in top-10 citrus-producing countries in 2016 (FAO 2017)

the recommended fertilizer rate (N, P_2O_5 or K_2O). The formula is shown below.

$$Fertilizer - saving\ potential\ (\%) = \frac{(F_{FP} - F_{RE})}{F_{FP}} \times 100\% \quad (2)$$

where F_{FP} is the fertilizer rate of farmers' practices and F_{RE} is the recommended fertilizer rate for given citrus orchard.

RESULTS

Citrus Yield Gap between China and Other Major Citrus-producing Countries

FAO statistics showed that the top-10 countries for citrus-producing produced citrus fruits with 109.1 million tons, making up 74.5% of global citrus production in 2016 (FAO, 2017). More over, China's citrus production along accounts for a quarter of the world (FAO, 2017). On the other side, the averaged citrus yield of China is as low as 14.6 t/ha which is similar with that of Mexico, but higher than that of India and Nigeria (**Fig. 1**). This level is still lower than the world average yield and there is a gap of more than 10 t/ha compared with Turkey, Brazil and USA. This also indicates that there is a great potential to increase the average citrus yield of China in future.

Citrus Fertilization Practice in China and Other Major Citrus-producing Countries

By summary of the published literature, the status of farmers' practice of citrus fertilization in nine major citrus-producing provinces in China was evaluated (**Table 1**). The results showed that the averaged inputs of N, P_2O_5 and K_2O was 485, 198 and 254 kg/ha, respectively. Citrus growers from Guangdong and Zhejiang provinces generally applied higher rates of NPK fertilizers than growers from other provinces. In average, the input ratio of N, P_2O_5 and K_2O fertilizer is 1.0:0.41:0.52. The literature-based yield from different provinces ranges from 15.3 to 38.6 t/ha with an average of 26.5 t/ha. The variation in yield and N fertilization also resulted in great difference in N use efficiency as indicated by PFP_N (**Table 1**). The PFP_N was ranged from 31.8 to 92.5 kg/kg, with an average of 54.6 kg/kg.

It is noticeable that the survey yield from literature data (**Table 1**) is obviously higher than the statistical yield from FAO (**Fig. 1**). The reason would be that newly planted citrus orchard in China increase at a speed of 86 thousand hectares per year during the last 15 years, and these non-bearing orchards or newly bearing orchards may lower the overall level of citrus average yield in China. Moreover, the literature statistics are mainly from the full bearing orchards. Thus, the following data including yield, fertilization rate and fertilizer use efficiency are based on the literature statistics.

The average citrus yield in China is lower than that in the United States, Brazil and South Africa (**Tables 1** and **2**), which is consistent with the FAO data (**Fig. 1**). However, the application rate of NPK fertilizer in these three countries is only 160~250, 40~100 and 140~200 kg/ha, respectively. And these rates are obviously lower than that in citrus orchard of China (**Tables 1** and **2**). The high yield and the low rate of NPK fertilizer in United States, Brazil and South Africa has led to advanced N use efficiency (PFP_N) by 150~200 $kg{\cdot}kg^{-1}$ (**Table 2**), which is 2~3 times higher than that of

Table 1. Farmer practice of citrus fertilization in major citrus-producing provinces of China

Province	Yield (t/ha)	Fertilization rate (kg/ha)			PFP_N (kg/kg)	Sample number	Reference (Annex I)
		N	P_2O_5	K_2O			
Fujian	33.3±13.7	361±267	194±108	235±153	92.5	34	[1-4]
Hubei	26.3±12.3	316±92	149±37	230±91	83.2	346	[5-11]
Zhejiang	38.3±1.1	539±162	225±72	223±21	71.0	27	[12-15]
Hunan	26.2±15.5	422±246	223±132	328±186	61.9	21	[16-18]
Chongqing	20.1±13.5	328±233	214±156	235±199	61.1	452	[3,19-22]
Guangxi	21.4±13.9	398±125	198±99	181±128	53.7	7	[23-25]
Sichuan	19.3±5.2	397±171	176±76	200±134	48.5	5	[3,20,26-27]
Jiangxi	15.3±0.4	395±71	196±42	235±31	38.8	30	[28-31]
Guangdong	38.6±4.2	1212±594	205±112	418±133	31.8	4	[32-34]
Mean	26.5±8.5	485±280	198±24	254±73	54.6	926	

Table 2. Fertilization rate and PFP_N in citrus orchards of selected major citrus-producing countries

Country	Yield level (t/ha)	Fertilization rate (kg/ha)				PFP_N (kg/kg)		Reference
		N_{Lower}	N_{Upper}	P_2O_5	K_2O	N_{Lower}	N_{Upper}	
USA	30~40	160	200	40	180	188	200	Obreza and Morgan (2008)
Brazil	25~30	160	200	100	140	156	150	Mattos *et al.* (2012)
South Africa	30~40	200	250	50	200	150	160	De Villiers and Joubert (2003)
India	10~15	160	350	135	250	63	43	Srivastava (2013)

Table 3. Recommended fertilizer rate for producing one ton of citrus fruit in China

Region	Variety	Recommended fertilizer rate (kg/ton fresh fruit)			Reference (Annex I)
		N	P_2O_5	K_2O	
Zhejiang	Satsuma mandarin	12.5	7.5	10.0	[13]
Zhejiang	Satsuma mandarin	11.5	5.7	6.8	[31]
Hubei	Sweet orange	8.0	4.0	5.6	[35]
Hunan	Satsuma mandarin	7.1	4.4	5.9	[17]
Fujian	Satsuma mandarin	10.6	3.5	8.7	[2]
Fujian	Sweet orange	10.6	2.5	6.0	[2]
Jiangxi	Sweet orange	9.0	4.5	9.0	[28]
Jiangsu	Satsuma mandarin	9.5	7.1	6.8	[36]
-	Satsuma mandarin	8.0	6.5	8.0	[37]
Chongqing	Sweet orange	13.3	8.1	13.3	[22]
Jiangxi	Sweet orange	11.0	5.6	7.2	[38]
-	Citrus	13.3	4.7	10.0	[39]
Mean		10.4±2.0	5.2±1.6	8.1±2.1	/

Table 4. Current potential for saving chemical fertilizer in citrus orchards of China

Region	Citrus-planting area (ten thousand hectare)	Fertilizer consumption (ten thousand tons)			Requirement under recommendation in China (ten thousand tons)			Fertilizer saving (ten thousand tons)		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Fujian	18.0	6.5	3.5	4.2	3.6	2.2	2.9	2.9	1.3	1.3
Hubei	24.4	7.7	3.6	5.6	4.9	2.9	3.9	2.8	0.7	1.7
Zhejiang	10.9	5.9	2.5	2.4	2.2	1.3	1.8	3.7	1.2	0.7
Hunan	40.0	16.9	8.9	13.1	8.0	4.8	6.4	8.9	4.1	6.7
Chongqing	16.1	5.3	3.5	3.8	3.2	1.9	2.6	2.1	1.5	1.2
Guangxi	21.7	8.6	4.3	3.9	4.3	2.6	3.5	4.3	1.7	0.5
Sichuan	27.2	10.8	4.8	5.4	5.4	3.3	4.3	5.4	1.5	1.1
Jiangxi	31.7	12.5	6.2	7.5	6.3	3.8	5.1	6.2	2.4	2.4
Guangdong	25.5	30.9	5.2	10.6	5.1	3.1	4.1	25.8	2.2	6.6
Total	215.5	105.1	42.5	56.7	43.0	25.9	34.6	62.1	16.7	22.2
Fertilizer-saving potential (%)								59.0	39.2	39.2

China (**Table 1**). Compared with India which is another big and fast developing countries, the citrus yield level in China is higher than that of India, whereas the N rate in China is also higher than that of India, resulting similar PFP_N (**Tables 1** and **2**). These indicate that excessive use of fertilizers and low yield is together responsible for the low fertilizer use efficiency during citrus production in China. And these also indicate that there is a great potential for increase of citrus yield with reducing input of chemical NPK fertilizer, a recent national policy of "zero-growth of chemical fertilizer use" in China.

Current Fertilizer-saving Potential for Citrus Production in China

In China, the recommended rates of NPK fertilizer for producing one ton of citrus fruit are 10.4, 5.2 and 8.2 kg in average (**Table 3**). Under the scenario of current yield level (26.5 t/ha), the recommended rate of NPK fertilizer are 275, 138 and 215 kg/ha, respectively. Therefore, the current fertilizer-saving potential for citrus production in China is huge, basing on current citrus yield, farmers' fertilization practices and fertilizer recommendation (**Tables 1**, **3** and **4**). Overall, 0.621, 0.167 and 0.222 million tons of N, P_2O_5 and K_2O could be saved each year in major producing areas of citrus in China. Thus, the current fertilizer-saving potential of NPK fertilizer is 59.0, 39.2 and 39.2%, respectively. At regional scale, Guangdong province followed by Hunan and Jiangxi provinces has the largest potential for fertilizer-saving.

Evaluation of High Yield and High Efficiency of Citrus under Different Scenarios

The planting area of citrus in China is 2.52 million hectares in 2016, thus the expected annual demand of NPK fertilizer is about 1.22, 0.49 and 0.64 million tons (**Table 5**), according to the averaged yield and farmers'

Table 5. Evaluation of high yield and high efficiency of citrus production in China under different scenarios

Scenarios	Citrus yield (t/ha)	Predicted fertilizer requirement (ten thousand tons)			PFP_N (kg/kg)	Benefit of increasing yield (million tons)	Fertilizer saving (ten thousand tons)			
		N	P_2O_5	K_2O			N	P_2O_5	K_2O	Total
Current yield level in China	26	122.3	49.9	64.0	54.6	/	/	/	/	/
Regular yield in advanced countries*	40	47.2	20.2	47.2	213.6	35.3	75.1	29.7	16.8	121.6
Intermediate yield in advanced countries	50	51.1	25.2	51.1	246.9	60.5	71.2	24.7	13.0	108.9
High yield in advanced countries	60	54.9	30.3	54.9	275.4	85.7	67.4	19.7	9.1	96.1
High yield in China	60	113.4	37.8	88.2	133.3	85.7	8.8	12.1	-24.2	-3.3

*Note: The application rate of N, P_2O_5, K_2O were 187, 80, 187 kg/ha, 203, 100, 203 kg/ha, 218, 120, 218 kg/ha under the levels of 40 t/ha, 50 t/ha, 60 t/ha in advanced citrus-producing countries (here indicate USA, Brazil and South Africa), respectively (De Villiers and Joubert 2003, Mattos *et al.* 2012, Obreza and Morgan 2008)

fertilization practices (**Table 1**). However, the yield and fertilizer input level may change with different scenarios in future. By adopting the scientific management and rational fertilizer input (in average, 4.12, 2.00 and 4.12 kg of N, P_2O_5 and K_2O fertilizers is applied for producing one ton of citrus fruit) in advanced citrus-grown including USA, Brazil and South Africa (De Villiers and Joubert 2003, Mattos *et al.* 2012, Obreza and Morgan 2008), 61.4, 59.5 and 26.3% of current evaluated NPK fertilizer could be saved when averaged citrus yield in China reaches 40 t/ha (**Table 5**). Under such scenario, citrus growers could gain substantial yield benefit and saving fertilizer cost with remarkably high N use efficiency (**Table 5**). More optimistic scenarios could be addressed further when modern technology such as fertigation is applied. Moreover, the current fertilizer consumption is still enough to support high yield levels of 60 t/ha (**Table 5**), if fertilization recommendation in China is followed (**Table 4**). In this case, the proportion of NPK fertilizer required should be adjusted by reducing N and P input and increasing K input (**Table 5**).

DISCUSSION

Reasons for Over Fertilization of Citrus Orchards in China

Over fertilization is the most important factor for the low efficiency of fertilizer utilization in citrus and other crops in China. Influenced by traditional concepts such as "more fertilizer, more production", the government and farmers input excessive chemical fertilizers in order to obtain high yield especially in the economic developed areas in China (Zhang *et al.* 2008). This phenomenon is more serious in the fruit trees. For example, the averaged amount of N fertilizer applied in apple orchards in Shaanxi province in China is 671 kg/ha, which is almost two times higher than the recommended rate in China (*Zhao et al.* 2012). A recent farmers' survey showed that the averaged amounts of N, P_2O_5, and K_2O fertilizer in major citrus-producing areas in China are 513, 376 and 404 kg/ha (Liang 2017), indicating the degrading trend than previous studies (**Table 1**). Accordingly, soil N and P surplus in citrus orchards in the Three Gorges Reservoir area is more than 350 kg/ha, threating the soil, water and environments (Zhou *et al.* 2011). Therefore, there is a substantial gap between China and other advanced countries in terms of fertilization and management in citrus orchards.

To realize zero-growth of chemical fertilizer use in citrus production in China, it is urgent to understand why the Chinese farmers use so much NPK fertilizer in citrus orchards. The reasons are discussed as followed. Firstly, economic benefit drives high NPK input. The relatively high economic value of cash crops including fruits industry generally has a larger amount of fertilizer. In many regions, farmers are encouraged to grow high-value crops in order to develop the economy and adjust agricultural planting structure. Driven by economic interests, farmers invest fertilizer heavily in citrus and other high added value crops (Zhang and Ma 2000). Secondly, a mass of nutrient loss due to poor site condition of citrus orchards. The major citrus producing areas in China are mainly distributed in the hilly regions in the South China, and the citrus orchards generally have problems such as large slope, poor soil condition, complex topography, soil erosion and seasonal drought (Shen 2005). By facing low soil fertility of the citrus orchard including nutrient loss, low capacity of soil and water reserving, the farmers are inclined to overuse fertilizers for solving these potential problems due to lacking scientific training and other measurements. Thirdly, the proportion of fertilizer and the method of fertilization are not reasonable. Most farmers apply chemical fertilizer only, while ignoring the application of organic manure. Even so, there is a widespread phenomenon that N fertilizer is heavily used while P and especially K fertilizers are insufficient in many cases. In addition, nearly half of the farmers top-dress the fertilizers without plowing (Liu *et al.*

2002). Such fertilizing method is not matched with the root distribution in soil profile, thus is not efficient to satisfy the nutrient requirement by the roots. For example, in order to operate conveniently, some farmers directly scatter fertilizer near the base of trunk which not only causes the toxic effect to the root, but also wastes the fertilizer and reduces the use efficiency of fertilizer. Fourthly, the laws about cropland nutrient management are not established in China. There are related policies and regulations to guarantee the construction of ecological agriculture systems in many developed countries. In the United States, the farmers who pollute the environment by fertilizers and pesticides have to pay taxes to the state agriculture department (Zheng and Shi 2007). In Europe, there are also relevant laws and regulations that N fertilization higher than 170 kg/ha is for forbidden in farmlands. Under the premise of developing economy as the first priority during last few decades, China's law on agricultural system and environmental protection started late, leading to some defective consequences that the China government is now on the way to improve. Fifthly, the education level and professional knowledge of current farmers are generally low. The fast development of cities and industries attracted rural people to leave their hometown, creating a shortage of rural labors in China. As a consequence, more and more old people stranded in rural areas engage in agricultural production, facing the phenomenon of village aging and hollowing-out (Tang 2009). The aging of farmers is bound to restrict their knowledge and professional level which has a significant correlation with the use of fertilizers. With the increase of the average number of education years, the amount of fertilizer used by farmers had a trend to decrease (Ma *et al.* 2011).

Strategy to Realize High Yield and High Nutrient Use Efficiency of Citrus Production in China

The ultimate goal of both high yield and high nutrient use efficiency through technology integration and innovation is to achieve the equilibrium of resources input and output, to synchronously realize the increase of crop yield, efficient resource use, environment security, increasing farmers' income, promoting the sustainable development of agriculture and society (Zhang *et al.* 2012). It's clear that citrus production in China still has substantial gap with the goal of high yield and high efficiency.

The high fruit yield, high nutrient efficiency and ecological security of citrus production system are achieved largely depend on fertilization management.

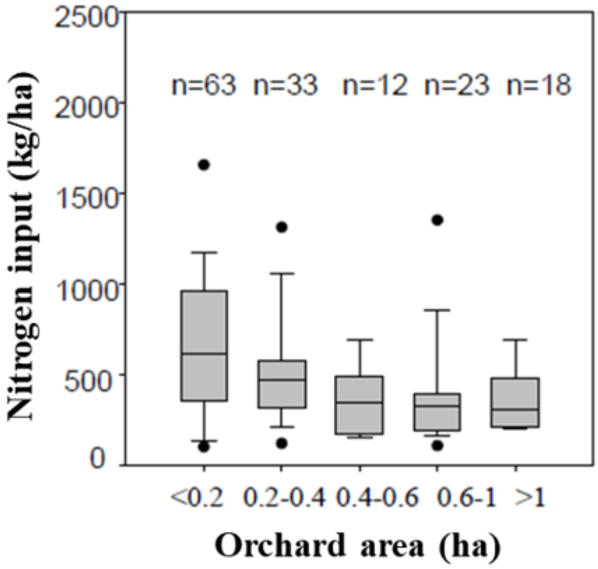

Fig. 2. The relationship between orchard area and nitrogen input in Chongqing, China

By further understanding the status of citrus nutrient management in China including excess, unbalanced, improper fertilization, and the underlying reasons, strategies are suggested to promote zero-growth of chemical fertilizer use and green development of citrus production in China.

Firstly, to promote moderate land transfer for reducing fertilizer input. The excessive amount of fertilizer application especially N application in China is mainly due to the lack of knowledge about the crop nutrient requirement and fertilizer characteristics, and farmer apply fertilizer by their experience without considering cost-effectiveness ratio (Cui *et al.* 2010, 2018). The scales of citrus orchards in China are generally smaller than 0.2 hectare, while large and medium-sized orchards are rare. According to the survey results of 149 citrus orchards in Chongqing, China, the area of the citrus orchards and the N application rates showed an obviously negative trend (**Fig. 2**). For example, the N rate was decreased from 600 kg/ha of the smaller orchards (<0.2 hectare) to nearly 300 kg/ha of the bigger orchards (>0.6 hectare). More than 42% of citrus orchards are less than 0.2 hectare, whereas percentage of orchards with more than 1 hectare is only 12%. As a comparison, a striking feature of the Brazilian and American citrus industries is highly intensive and industrialized, with an average production scale of 16.2 hectare (Chen *et al.* 2014); In Sao Paulo, Brazil, 8% of citrus farms provide two-thirds of the nation's citrus production (He and Qi 2009). Therefore, appropriate land transfer and intensification of citrus production would reduce N and other

Table 6. Relationship between citrus yield and soil organic matter in surveyed orchards in Chongqing, China in 2013 (n=459)

Classification of SOM content (g/kg)	≤5.0	5~10	10~15	15~30	≥30
Sample proportion (%)	2.2	14.4	60.3	17.9	5.2
SOM (g/kg)	4.3	7.6	13.5	26.9	32.3
Yield (kg/tree)	15.7	18.9	30.4	45.2	45.3

fertilizer input, maintain relatively high yield and improve fruit quality and nutrient use efficiency.

Secondly, to improve soil quality and soil fertility in citrus orchards. The fertility of soil is closely related to the growth, development and vigor of the root system. Both soil fertility of citrus orchard and effective absorption area of the root system is enhanced by applying soil improvement materials (*Ye et al.* 2014). Compared with clearing tillage in most citrus orchard in China, green cover crop in citrus orchard has advantages in increasing SOM content, improving soil physical and chemical properties, enlarging soil water storage capacity to solve the water loss during seasonal drought in citrus orchard soil of China. Moreover, studies have shown that the soil available N, K, zinc, iron and other nutrient contents are significantly increased after two years' cultivation of cover crops in citrus orchard (Li and Yi 2005).

Thirdly, to increase soil organic matter by organic fertilizer application. Organic fertilizer contains a variety of nutrition elements, organic carbon, useful microbe groups and active enzyme which can be used by crops. It can also improve soil structure, activate soil nutrients, improve soil fertility, enhance beneficial microbial activity and thereby ensure both crop yield and quality (Feng 2013). Using organic fertilizers for nutrient recycling is a major feature of China's traditional agriculture, and is also a key foundation for the development of circular economy, sustainable agriculture and green development (Liu 2007). Many studies have shown that combined application of organic and inorganic fertilizer can achieve the double effect of high yield and fertilizer-saving, which is helpful to realize sustainable development of agriculture (Sanz-Cobena *et al.* 1995). For example, organic fertilizer application in citrus orchard on slope land decreased N runoff, improved the growth status of citrus trees and increased both citrus yield and quality (Xie *et al.* 2010). According to farmer survey (n=459) and soil test of citrus orchards with 5-year Hamlin in Chongqing, China, we found that SOM is obviously and positively correlated with citrus fruit yield until the SOM is higher than 30 mg/kg (**Table 6**). However, nearly 80% of SOM in citrus orchards of Chongqing is lower than 15g/kg, indicating that soil organic matter is still one of the major factors that limit citrus fruit yield.

Fourthly, to balance fertilization. The target amount of N fertilizer is set according to target fruit yield, and then the target amount of P and K fertilizer is set according to their ratio to N fertilizer (Shen and Liu 2013, Zhang *et al.* 2009). For example, N 300 kg/ha, P2O5 120 kg/ha and K2O 300 kg/ha is recommended for a moderately fertile orchard with target yield of 30 t/ha. Later on, these NPK fertilizers should be splited into three or four times according to citrus phenological period at given region. Such splited application including budding stage, fruit enlarging stage and harvesting stage can match citrus nutrient requirement better, reduce the potential risk of nutrient loss by runoff, leaching or volatilization, and also reduce the toxification to root by overused and concentrated application, and thus improve the NPK use efficiency (Alva *et al.* 2006, Quinones *et al.* 2007). In addition, soil micronutrient deficiency especially calcium, magnesium, boron and zinc deficiency in citrus orchard on acid soils should be tested by an interval of 2 or 3 years which is used as a measure of micronutrient application (Scholberg *et al.* 2002, Zhang *et al.* 2009).

Fifthly, to develop fertigation stytem to reduce fertilizer rate while meet water requirement in citrus orchard in China. Production practice shows that coupling fertilizer and water by fertigation technology is becoming an integrated management measure in horticultural system because of its obvious advantages and characteristics such as fertilizer-saving, water-saving, pesticide-saving, labor-saving, high yield, high efficiency and low environmental pollution (Srivastava and Malhotra 2017). China's citrus orchards are mainly distributed in hilly area of south China with shallow soil profile, poor water retention capacity and seasonal drought during fruit developing stage. Therefore, fertigation system could effectively solve these problems to meet citrus nutrient and water requirements. For example, compared with traditional fertilization practices in southwest China, fertigation technology increased the amount of citrus fruit by 79 fruits per tree, increased the fruit yield by 39%, reduced 80% of fertilizer input and 90% of labor cost, and finally increased the income by 40,000 RMB per hectare (Han and Xiang 2015). At the same time, China's agricultural sector should strengthen the education and training of agricultural practitioners and promote the development and popularization of agricultural technology.

CONCLUSIONS

Our campaign aims to reduce fertilizer demand and raise usage efficiency, following concerns about inefficient use and potential ecological damage. Farmer fertilizer input especially N input in citrus orchards of China are higher than recommended rate by experts in China, and is 2~3 times higher than that in developed countries with advanced citrus industry such as USA, Brazil and South Africa. Furthermore, the citrus yield per area in China is varied and low. Therefore, both high fertilizer input and low citrus yield has contributed to low nutrient use efficiency with a PFP_N range of 43~73 kg/kg which only counts a quarter of that in USA and Brazil. On the other hand, more than 50% of current consumed chemical fertilizer for citrus production in China could be saved by adopting expert recommendation or improving fertilization technology (e.g., fertigation system). These findings thus illuminate that it is feasible to realize zero-growth of chemical fertilizer use in citrus production in China. In future, strategies including moderate land intensification, improvement of soil fertility and quality by soil amendment, organic fertilizer and green cover crops, updating fertilizer product and fertilizing technology, strengthening the education and training of citrus-producing practitioners would be useful to realize zero-growth of chemical fertilizer use in China's citrus production with better yield. And this would be also a lesson for developing countries with aim to develop citrus industry.

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ANNEX

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