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Integrated nutrient management for sustainable agriculture in China

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Abstract:

China's economy has made great strides since 1949, and especially since China initiated economic reforms and the open-door policy in the 1980's. The growth in agricultural production has been one of the main national accomplishments. By 1999 China was feeding 22 % of the global human population with only 9 % of the world's arable land and per capita food availability reached the levels of developed countries. The use of fertilizers has played a crucial role, accounting for about 50 % of the yield increase. However, rapid economic growth has led to unprecedented resource exhaustion and environmental degradation. China's 'grain security' will face multiple pressures stemming from resource limitation, environmental pollution and population growth. The Chinese government regards agriculture as the primary field of development of the national economy in the 21st century. The optimal agricultural developmental path for China is to improve the ratio of resource utilization and protect the environment while guaranteeing the grain supply. The Chinese government is committing major resources to national research and extension programs, including a soil test and fertilizer recommendation project, a best nutrient management practices project and an integrated crop and soil management for high yield and high resource efficiency in major cropping systems.

This paper summarizes the trends in crop production and crop yields, fertilizer use and soil quality in China, and presents the approach of integrated nutrient management (INM) for improving crop productivity with efficient resource utilization and environmental protection. In INM approach, strategy is to emphasize the integrated use of nutrients from fertilizers, wastes and soil and environmental sources; managing nutrient according to different nutrients' specific characteristic; nutrient management should also be integrated with sound soil management practices and other farming techniques.

Key words

Higher yield, efficient resource utilization, integrated nutrient management, crop systems

1 Accomplishments and challenges in Crop production

Since 1949, especially when China initiated economic reforms and the open-door policy in the 1980's, China's economy has made great strides. The growth of agricultural production has been one of the main accomplishments of the country. Cereal yield increased steadily from 2041 kg/ha in 1961 to 6432 kg/ha in 2007 for rice, from 557 kg/ha in 1961 to 4607 kg/ha in 2007 for wheat, and from 1139 kg/ha in 1961 to 5166 kg/ha in 2007 for maize, respectively (Fig. 1). The net increase was 349.1 Mt with an annual growth rate of 3.6 % which is higher

than the world mean growth rate of 2 %. China accounts for about 29 % of global rice production, 15 % of maize and 24 % of wheat production (National Bureau of Statistics of China, 2007; FAO, 2006).

Annual growth rates of cereal yields are gradually declining. Over the last 10 years rice yields have shown declining or stagnant trends in most rice production provinces and the average annual growth rate was -0.3 % from 1998 to 2006. Maize yields have been stagnant with a growth rate of only 0.3 %. Due to stagnant or decreasing yield trends as described above and decreasing cultivated area, a stagnant trend in cereal production can be clearly observed, especially over the last 8 years. For example, cereal production decreased from 198.7 Mt in 1998 to 182.6 Mt in 2006.

However, the grain yield potential of the current cereal varieties is far from actual yields obtained in China. For example, the average maize yields in farmers' fields are 5295 kg/ha in northeast China, 5055 kg/ha on the North China Plain, and 3990 kg/ha in hill areas in the south of China (National Bureau of Statistics of China, 2002-2006). While maize yields in regional new variety test experiments in the regions above are 8460, 7305, and 6690 kg/ha, increases of 60, 45, and 68 % over the average farm field yields in those regions. A similar situation can be found for wheat and rice. This also implies that there is great potential to increase cereal grain yields above current farmers' yields.

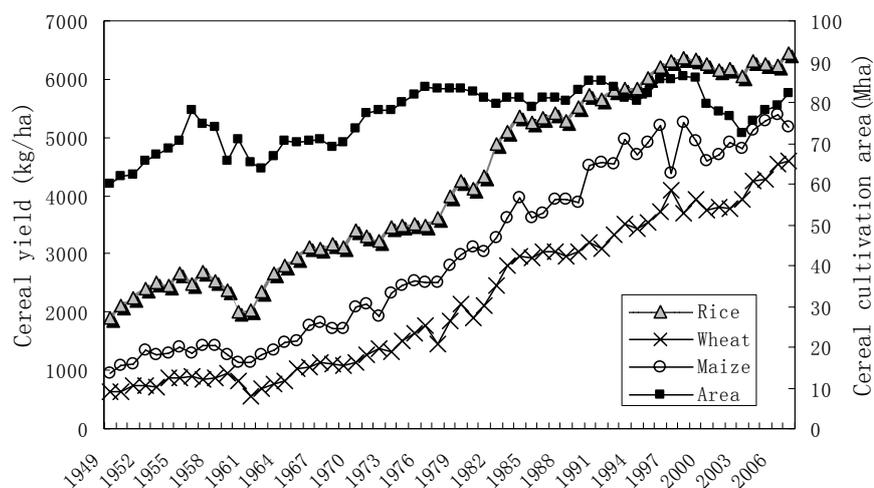


Fig 1. Changes in cereal production in China from 1949 to 2007. Total cereal harvest area and grain yields of rice, maize and wheat. Source: China Agriculture Yearbook 1961-2006.

To meet the demand for grain and to feed a growing population on the remaining arable land by 2030, crop production must reach 5.8 Mt and yield has to increase by 2 % annually in China. This is a great challenge to China for the decades to come.

2 Fertilizer utilization and efficiency in major cereal crop systems

On the nutrient utilization side, China has a long tradition over thousands of years of recycling organic materials to maintain relatively high yield levels and prevent soil fertility from declining. Mineral fertilizers were introduced in the 1950s and their use has increased rapidly. The inputs of fertilizer N, P and K increased almost linearly from 8.9, 2.7 and 0.4 Mt in 1980 to 35.4, 11.5 and 7.5 Mt in 2007. The total consumption of chemical fertilizers in China exceeded 54.4 Mt in 2007, nearly 35% of the total global consumption (National Bureau of Statistics of China, 1949-2007). Concomitantly, the contribution to total nutrient supply from organic manures decreased from almost 100% in 1949 to only 35% in 2001. For example, applied organic manures accounted for 18% of N, 28% of P and 75% of K overall in 2000.

Nutrient (NPK) efficiency is quite low in China. For example, the partial factor productivity of applied N is 54.2 kg/kg for rice, 43.0 kg/kg for wheat and 51.6 kg/kg for maize, respectively. Recovery efficiency of N (% fertilizer N recovered in aboveground crop biomass, REN) for cereal crops was 35% on average in the 1990's. However, this value has gradually reduced since then and the current REN is 28.3% for rice, 28.2% for wheat and 26.1% for maize (Table 1), all of which are lower than the world values (40-60%).

Tab. 1 Fertilizer N application rates, grain yields and various nutrient use efficiencies for rice, wheat and maize (Zhang et al, 2008)

Crop	Samples	Fertilizer rate (kg/ha)	Yield (kg/ha)	PFP (kg/kg)	RE (%)
Rice	179	150	6835	54.2	28.3
Wheat	273	169	5721	43.0	28.2
Maize	215	162	7045	51.6	26.1

Note: PFP : partial factor productivity of applied nutrient (kg grain per kg nutrient applied); RE: recovery efficiency of nutrient (% fertilizer nutrient recovered in aboveground crop biomass)

The low nutrient use efficiency may be attributed to fertilizer overuse and high nutrient loss resulting from inappropriate timing and methods of fertilizer application, especially in high yielding fields. As shown in Table 4, the average fertilizer N application rate for rice of 150 kg/ha is higher than in most countries and as much as 67% above the global average, but rates of 150–250 kg N/ha are common. Fertilizer application is often not based on real-time nutrient requirements of the crop and/or site-specific knowledge of soil nutrient status. For example, in rice production systems most farmers apply N in two split dressings (basal and top-dressings) within the first 10 days of the rice growing season (Fan et al., 2007). This large amount of fertilizer-N is prone to loss over an extended period because the rice plants require time to develop their root systems and a significant demand for N. In addition, nutrients derived from the environment and the soil are not taken into account when farmers determine fertilizer applied rates. This will also contribute to low nutrient utilization efficiency.

Irrational fertilizer utilization has led to environmental pollution. Losses of N and P through

leaching and run-off have led to drinking water pollution which affects 30 % of the population and results in eutrophication of 61 % of lakes in the country. Agricultural production also produces considerable emissions of nitrogen oxides to the atmosphere.

Optimization of nutrient application and achieving greater nutrient use efficiency at national and provincial levels are urgently required in China.

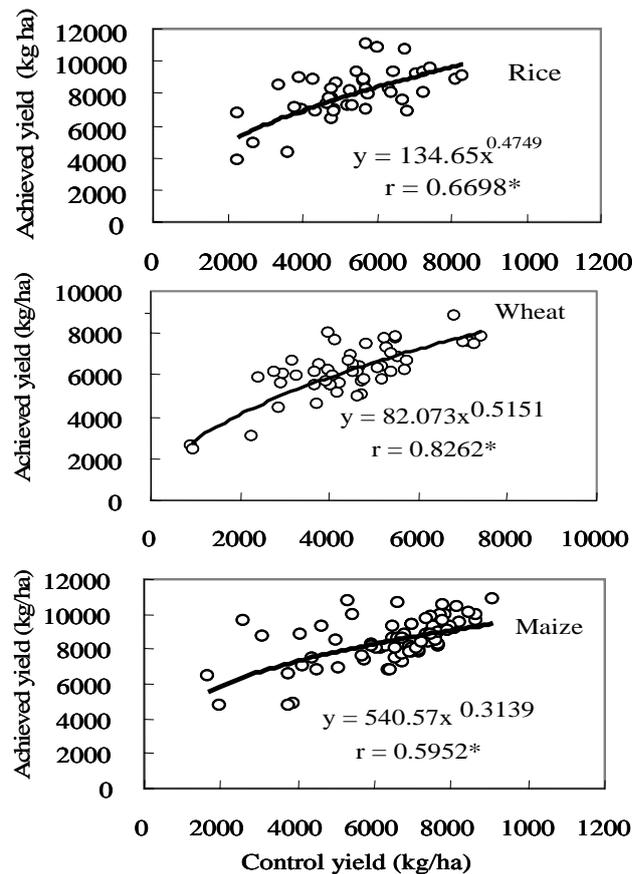


Fig 2. Relationship between achieved yields of rice, wheat and maize using best management practices and control yields with no fertilizer application. (Fan et al., 2009).

3. The statuses of soil fertility in crop production systems

Crop productivity is strongly dependent on soil quality. The soils with high inherent soil fertility consistently achieved significantly higher wheat, maize and rice yields than those with low inherent soil fertility (Fig 2). However, most arable land in China has low soil indigenous fertility so that it is difficult to achieve higher crop yields. Chinese scientists have classified the arable land based on grain yields into high, medium and low productivity land. Yields in higher productivity lands are usually 1-4 times and 2-6 times higher than those in medium and low productivity areas, respectively. Research is therefore required for a thorough understanding of the rates and causes of differences in soil indigenous fertility and subsequent effects on yields and input requirements to sustain yield increases in Chinese cropping systems.

The enhancement and maintenance of SOM are fundamental to soil quality improvement and ensuring global food security (Lal, 2004). However, SOC in Chinese cropping systems is low compared with Europe. For example, the average content of SOM in cropland is 10 g/kg in China compared with 25-40 g/kg in European countries and the United States. In spite the increasing SOC in most cropland in China, which was attributed to amendment with crop residues and organic manures together with synthetic fertilizer applications and the optimal combinations of nutrients and the development of no-tillage and reduced-tillage practices, especially in east, north, northwest, south and central China. However, soil degradation is a very serious problem in China. Soil degradation in China comprises 145 Mha or 7.4% of the world total. The loss of the SOC pool has been widely reported in Chinese croplands. Huang and Sun (2006) estimated that SOC in 31.4 % of monitoring sites in China suffered some loss due to water loss and soil erosion together with low inputs.

Because subtle changes in soil properties may lead to some reduction in the resource buffer provided by good soil quality, especially in high-yielding systems, it is very important to build up the SOC pool in Chinese croplands by appropriate management strategies such as returning large quantities of biomass to the soil and/or decreasing losses of SOC through erosion, mineralization, and leaching to give sustainability and high yields through improvement of soil quality.

4 Integrated nutrient management in crop production systems for reducing environmental risk while increasing crop productivity

China's 'grain security' will face multiple pressures stemming from resource limitation, environmental pollution and population growth. Given the low nutrient utilization efficiency and soil productivity, China must undertake a new step toward integrated nutrient management. Such an approach will focus on increasing crop productivity while optimizing nutrient use efficiency and soil quality.

The key points of this strategy include (a) integrated use of nutrients from fertilizers, wastes (from both agriculture and industry), and soil and environmental sources such as atmospheric deposition and irrigation water, (b) synchronization of nutrient supply and crop nutrient demand and application of different management technologies based on the characteristics of different nutrient resources, and (c) integration of nutrient management with sound soil management practices and other farming techniques such as use of high yielding cultivation systems, water-saving techniques, conservation tillage, and cover crops (Fan et al., 2008).

These new nutrient management systems can, on average, reduce N fertilizer inputs by 26%, save P fertilizer inputs by 20%, raise grain yields by 8%, and reduce N loss by 47 % compared to conventional agricultural practice as shown across 1517 experiments covering 12 cropping systems at 123 sites. Due to augmented plant productivity and increased return of crop residues, soil C sequestration will also increase and soil quality will be enhanced in the long term (Ju et al., 2009).

The main channels that have been used for communicating INM technologies with farmers and growers are the official extension service systems operated by central and local

governments and effective cooperation with the fertilizer industry. For instance, a Sinochem and China Agricultural University Research and Development Center established in 2003 focuses on new types of fertilizer exploitation, fertilizer market investigation, on-farm surveys of fertilizer applications, and training for staff in both the fertilizer industry and the official extension service. These arrangements have greatly facilitated the adoption of INM technology by farmers.

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