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# Transforming agriculture in China: From solely high yield to both high yield and high resource use efficiency

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ABSTRACT

The challenges facing agriculture in China are probably more severe than ever before. We have developed an integrated technology system in which the focus is on achieving both high crop productivity and high resource use efficiency ("double high" technology system) to ensure food security and environmental sustainability. The components comprise (1) significantly increased grain-yield through high-yield crop management, i.e. an optimal cropping system design and management well adapted to climate conditions; (2) greatly increased nutrient-use efficiency through root/rhizosphere management to optimize the nutrient supply intensity and composition in the root zone to maximize root/rhizosphere efficiency; (3) improved soil quality to ensure long-term food security by managing soil organic matter and eliminating soil physical, chemical and biological constrains and (4) enhanced agricultural sustainability through resource and environment management by increasing resource use efficiency, reducing nutrient losses and greenhouse gas emissions and minimizing negative ecological footprints. In our work in major agricultural regions of China, this system has been successfully tested and demonstrated through well-organized farmer associations, enterprises with improved products and government extension networks. The new "double high" concept has the potential to become an effective agricultural development path to ensure food security and improve environmental quality, especially in China and other rapidly developing economies where agricultural intensification must achieve and must be transformed from low-efficiency systems to achieving high yields with high resource use efficiency.



## 1. Problem and challenge

Although the past half-century has seen marked growth in food production, allowing for a dramatic decrease in the proportion of humanity that is hungry, the challenges facing agriculture today are even greater because increased global food production must occur while also protecting environmental quality and conserving natural resources. This challenge is particularly daunting in rapidly developing countries with high population density and limited agricultural land to feed that population, such as China, India, Bangladesh, Pakistan, Indonesia, and many others. They all achieved substantial yield increases from green-revolution technologies during the 1960s–1980s, but rates of gain in cereal yields have slowed down markedly in the past 10–20 years. Despite this decelaration in yield gains agricultural inputs such as nitrogen (N) and phosphorus (P) have continued to increase (FAO, 2010). For example, Chinese cereal grain yields increased by 65% from 1980 to 2010 while the use of chemical fertilizers increased by 512% during the same period (Fig. 1) (National Bureau of statistics of China, 1961–2010; Zhang et al., 2011, 2012a).

In some developed nations such as the USA, Germany or the UK, maintaining/improving environmental quality has been made a top priority with only secondary concern about crop production output because of high self-sufficiency and surplus of grain production in these nations. In most rapidly developing countries crop productivity must increase further because of continuing population increase and changing diet. In the past half-century, pursuing high yields with excessive and imbalanced nutrient resources has sometimes resulted in severe environmental problems such as eutrophication (Le et al., 2010), greenhouse gas emissions (Zheng et al., 2004), and soil acidification (Guo et al., 2010). For example, in the last 10 years (2000–2009), 54% of the global increase in chemical fertilizer consumption (~27 MT) has occurred in China (Zhang et al., 2012a). Often three times as much fertilizer N and P are applied in comparison to the amounts

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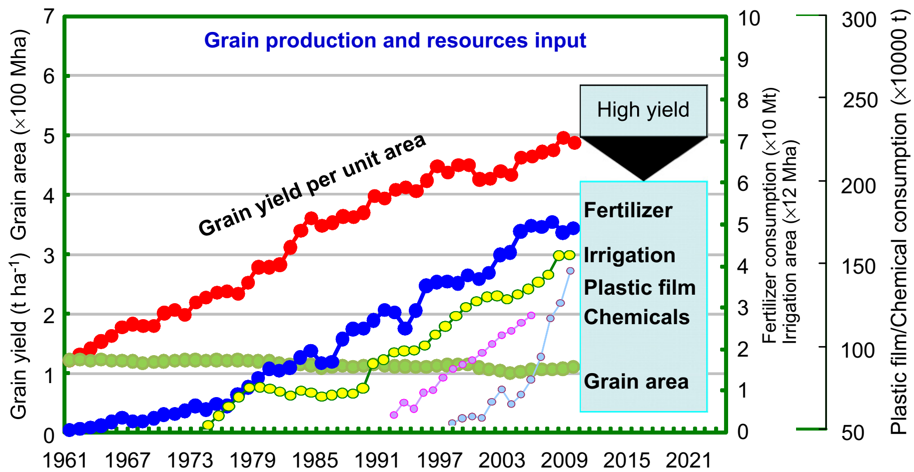


**Fig. 1.** Cereal grain yield in China has been merely secured by much higher input of resources including fertilizer, irrigation, plastic film and other chemicals. Data are based on the China Statistic Yearbook (National Bureau of statistics of China, 1961–2010 Zhang et al., 2011).

removed by crops, and this nutrient imbalance in turn drives environmental risk problems (Zhu and Wen, 1992; Zhang et al., 2008)

A further challenge is that in some rapidly developing countries crops are produced by hundreds of millions of farmers on small parcels of land. In China, the average area per farm is only 0.6 ha and individually managed fields are generally 0.1–0.3 ha (Chen et al., 2011). The scale of these individual farms makes use of many advanced agricultural technologies much more difficult.

Can we increase food production while also protecting environmental quality and conserving natural resources? The question must be confronted by agricultural scientists, policy-maker, and other stakeholders towards an agricultural development that will be characterized by being able to achieve sustainable high yields with high resource-use efficiency—a "double high" crop production concept.

## 2. From intensive to efficient high-yield crop production

Until recently, most agricultural paradigms in China have focused on increasing production using large resource inputs, especially water and nutrients, often to sacrifice the environment (Fan et al., 2012). For example, maize yields in 44 high-yield studies have doubled from 6.8 t $ha^{-1}$ with conventional farming practice to 15.2 t $ha^{-1}$ with high-yielding practices (Chen et al., 2011). However, the high yields in such research studies were achieved primarily by increasing fertilizer N inputs from 257 kg N $ha^{-1}$ in current farming practice to 774 kg N $ha^{-1}$, producing only 21 kg grain $kg^{-1}$ N and leaving an astonishing 457 kg N $ha^{-1}$ unaccounted for in the mass balance of N (Chen et al., 2011). On the other hand, many agroecological or environmental conservation strategies have increased nutrient use efficiency, but have not sought to increase food production (Chen et al., 2011; Fan et al., 2012). In previous studies, compared with farming practice, an in-season N management strategy based on soil mineral N ($N_{min}$) test reduced N fertilizer by 60% and 40% for wheat and maize but increased grain yields by only 4% and 5%, respectively (Cui et al., 2008a,b). To achieve food security and environmental sustainability, agricultural development in China must be transformed to address both challenges (Fan et al., 2012; Zhang et al., 2012a).

The path from intensive to efficient high-yield crop production in China needs to be aligned with the general development of the Chinese economy. In recent years, research in our group in China has focused on a conceptual model for more efficient, sustainable high-yield cropping and the specific technologies needed for that, with particular emphasis on cereal-based cropping systems in northern China (Fig. 2). Many scientific principles underlying this approach have been developed or proposed in other parts of the world as reported before (Campbell et al., 1995; Cassman, 1999; Cassman et al., 1996, 1999, 2002, 2003; Dobermann and Fairhurst, 2000; Dobermann and Cassman, 2005; Dobermann, 2007; Ladha et al., 2005), but they require adaptation to the needs of China, both in terms of scientific solutions and extension approaches. Hence, our activities during the past 12 years have focused on developing the pivotal components of this enhanced agricultural technology system and learning first lessons from how to apply this into practice. In this paper, we provide a brief overview of this research and we analyze what lessons we have learned and how they could be applied more generally to a sustainable intensification of agriculture in China and elsewhere.

Our approach is comprised of four major technology components:

### 2.1. Significantly increased grain yield through high-yield crop management to ensure food security

Today, grain yields could already be improved by 15%–20% compared to current farming practice through known agronomic and management practices to close existing yield gaps (defined as the difference between yield potential ceilings and the yields actually achieved by farmers). Although many modern crop varieties have been introduced, and sufficient (even excessive) N, P and K fertilizers are used in some regions, the yield gap is still large in China. For example, the simulated yield potential in main Chinese maize production areas averaged 16.5 t $ha^{-1}$ and the measured maximum yields were 15.4 t $ha^{-1}$, whereas the average farmer's yield was 7.9 t $ha^{-1}$ (48% of the yield potential) in 5584 farms (Meng et al., in press). The major factors explaining this gap are: (i) low efficiency of light and heat resource use due to low plant density, unsuitable sowing dates, short-duration varieties, and early harvest with incomplete grain filling; (ii) poor water and fertilizer management with either too much or too little and/or inappropriate timing; and (iii) other poor crop management practices, such as poor sowing conditions, large variability in stand uniformity, and improper plant protection. To narrow this gap, multidisciplinary understanding and cooperation among the disciplines of plant science, agronomy, soil science, and agro-ecology, resulting in a more integrated soil–crop system