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REVIEW

Transgenic approaches for improving use efficiency of nitrogen, phosphorus and potassium in crops

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Abstract

The success of the Green Revolution largely relies on fertilizers, and a new Green Revolution is very much needed to use fertilizers more economically and efficiently, as well as with more environmental responsibility. The use efficiency of nitrogen, phosphorus, and potassium is controlled by complex gene networks that co-ordinate uptake, re-distribution, assimilation, and storage of these nutrients. Great progress has been made in breeding nutrient-efficient crops by molecularly engineering root traits desirable for efficient acquisition of nutrients from soil, transporters for uptake, redistribution and homeostasis of nutrients, and enzymes for efficient assimilation. Regulatory and transcription factors modulating these processes are also valuable in breeding crops with improved nutrient use efficiency and yield performance.

Keywords: nutrient use efficiency, nitrogen, phosphorus, potassium, transgenic approach, crop

1. Current status of fertilizer use in China

Worldwide, the production of food has remarkably increased since the Green Revolution in the late 1950s. The success of the Green Revolution largely relied on chemicals including fertilizers. The global consumption of fertilizer experienced an approximate five-fold increase since 1961, and China had a much faster increase over the same period. China used only 0.73 million metric tons (Mt) of fertilizer ($N+P_2O_5+K_2O$) in 1961, and increased their usage to 60.16 Mt in 2014 (Fig. 1-A), accounting for one third of total world consumption. Compared to the fast growth of fertilizer usage, the production of food experienced a slower gain. From 1980 to 2014 in China, fertilizer consumption nearly doubled twice (from 15.33 to 60.16 Mt, Fig. 1-A), whereas food production did not quite double (from 32.06 to 60.70 Mt, Fig. 1-C) and the grain yield per hectare of rice (*Oryza sativa*), wheat (*Triticum aestivum*), and maize (*Zea mays*) increased by 65, 174, and 86%, respectively (Fig. 1-B). The fertilizers used on rice, wheat, and maize crops in China accounted for 31.0, 24.0, and 26.4% of the global consumption, respectively (Fig. 1-D); however, the production of rice, wheat, and maize in China accounted for 28.1, 17.3, and 20.8% of the world total, respectively. These data indicate that China does not presently use fertilizers efficiently in the production of food.

China also now uses much more fertilizer per hectare than other countries. In 2013, China applied 328.5 kg of fertilizer per hectare, approximately 1.5-fold higher than

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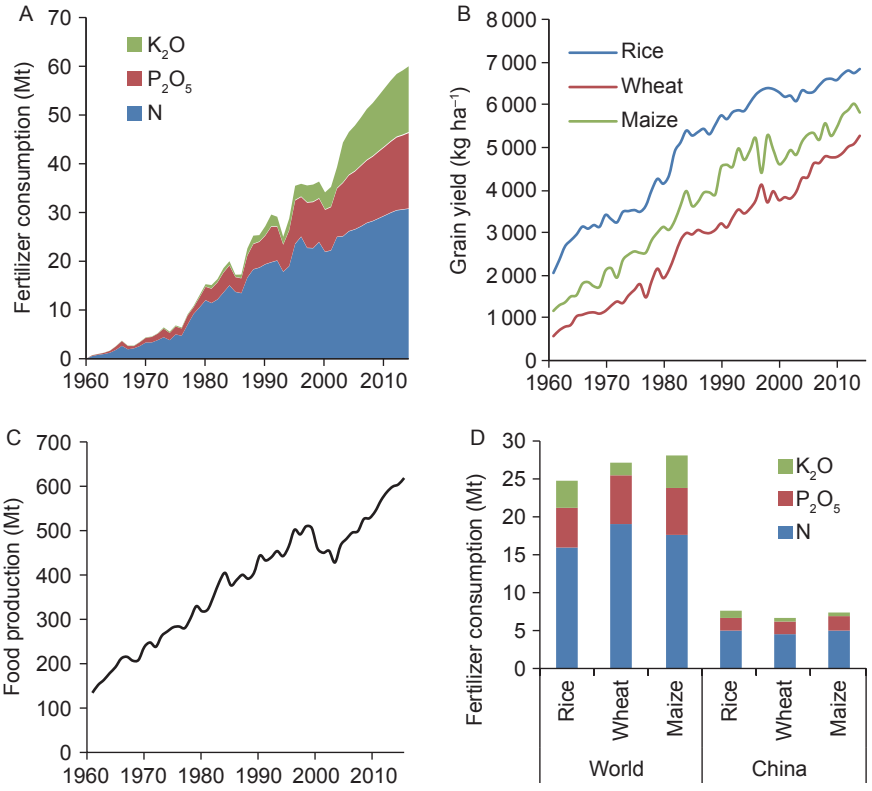

Fig. 1 Food production and fertilizer consumption in China. A, annual fertilizer consumption in China. B, grain yield of rice, wheat, and maize in China. C, food production in China. D, fertilizer used by rice, wheat, and maize in 2011. Data in A were collected from FAOSTAT (http://www.fao.org/home/en); data in B and C were collected from the National Bureau of Statistics of China (http://www.stats.gov.cn/); data in D were from Heffer (2013).

the world average, and that of the U.S. and the European Union. Over-application of fertilizer can cause adverse impact on environmental quality. A report revealed that China accounts for approximately 33–36% of excess nitrogen (N) and phosphorus (P) input and its croplands emit 28% of all N_2O (West *et al*. 2014). Studies from Chinese scientists also support the large impact of fertilizers on the environment, such as soil acidification (Guo *et al*. 2010), eutrophication of water bodies (Zhang *et al*. 2013), and enhanced greenhouse gasses emissions and N depositions (Liu X J *et al*. 2013). Therefore, it is urgent to develop sustainable agricultural systems that use fertilizers more economically, efficiently, and in an environmentally friendly manner. To achieve this goal, systematic approaches are required, including optimizing management practices (Chen *et al*. 2014) and breeding crops with improved nutrient use efficiency (Tilman *et al*. 2002; Good *et al*. 2004; Zhang 2007; Tian *et al*. 2012).

2. Strategies for improvement of nutrient use efficiency

Nutrient use efficiency is a combination of nutrient uptake efficiency (acquisition of nutrient from soil) and nutrient utilization efficiency (higher dry matter production per unit of nutrient taken up), and is coordinated by gene networks that mediate the uptake, re-distribution, assimilation, and storage of nutrients (Fig. 2). Plant roots are the main site

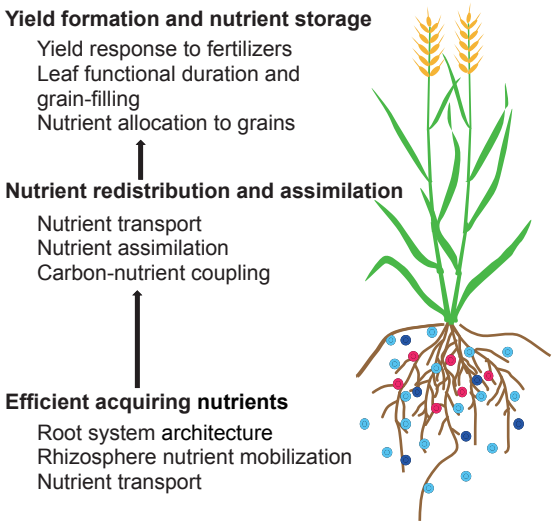

Fig. 2 Processes for efficient use of nutrients.