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Nutrient Efficiency of Winter Oilseed Rape in an Intensive Cropping System: A Regional Analysis

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ABSTRACT

Fertilization is essential for oilseed rape because it is sensitivity to nutrient deficiency, especially for winter oilseed rape (*Brassica napus* L.). To investigate regional nutrient efficiency and nutrient uptake-yield relationship of winter oilseed rape in an intensive cropping system, this study used data from 619 site-year on-farm experiments carried out in the winter oilseed rape planting area of the Yangtze River Basin, China from 2005 to 2010, with large yield in the range of 179–4 470 kg ha^{-1}. Currently recommended application rates of N, P and K fertilizers increased rapeseed yield at different levels of soil indigenous nutrient supply (INS) in this region. Boundary values of plant nutrient uptake were established to analyze the nutrient uptake-yield relationship of winter oilseed rape (internal nutrient efficiency), *i.e.*, 128 kg N ha^{-1}, 24 kg P ha^{-1}, and 122 kg K ha^{-1}. The internal nutrient efficiency declined by 48.2%–64.1% when nutrient uptake exceeded the boundary value, resulting in excessive nutrient uptake (*i.e.*, low yield response with high nutrient uptake), especially for K. In the intensive cropping system, agronomic efficiencies of N, P, and K were 5.9, 3.4, and 3.6 kg kg^{-1}, and recovery efficiencies of N, P, and K were 35.6%, 24.1%, and 36.8%, respectively. These findings showed that the fertilization rate should be optimized by considering INS, nutrient status, and nutrient efficiency of winter oilseed rape. In this study, considering the lower yield improvement to high K uptake levels and low K fertilizer efficiency, application rate of K fertilizer should be reduced since soil K deficiency has already been mitigated.

Key Words: agnomic efficiency, fertilization, indigenous nutrient supply, internal nutrient efficiency, nutrient uptake, recovery efficiency, regional scale, yield

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With the world's human population increasing and the related environmental and energy challenges, the demand for oilseed rape, an important source of edible oil and biodiesel, is growing substantially (Kim *et al.*, 2013). The Yangtze River Basin of China is a major production region with both planting area and rapeseed yield accounting for approximately one fifth of the world (FAO, 2013; National Bureau of Statistics of China, 2013). Farmers in the Yangtze River Basin plant two or three crops per year. They plant winter oilseed rape in rotation with rice, cotton or soybeans; this limits the time for plant growth and the supply of soil nutrients available for plant production (Degenhardt and Kondra, 1981; Zhang *et al.*, 2006). Thus, improving rape plant growth in this intensive cropping system is critical to ensuring the stability of rapeseed yield and the production of edible oil.

A better understanding of the effects of fertilizer, especially as it relates to nutrient efficiency in the intensive cropping system, is needed to improve fertilization management in the cultivation of oilseed rape (Cassman *et al.*, 2002; Deng *et al.*, 2012). New data could tell us how nutrient efficiency changes with the current application rates of N, P, and K fertilizers under different indigenous nutrient supplies (INS) in soil and how to optimize the fertilizer rate based on nutrient efficiency. Previous studies that estimated nutrient requirements of oilseed rape have primarily been demonstrated in site-specific field experiments, while data related to the regional nutrient uptake-yield relationship for oilseed rape remain unavailable across widely differing farm environments and in intensive cropping systems (Hocking and Stapper, 2001; Rathke *et al.*, 2005; Brennan and Bolland, 2007; Schulte auf'm Erley *et al.*, 2011). This shortage of information makes it difficult to develop guidelines for fertilization management for farmers. In the intensive cropping system, 619 site-year on-farm experiments were conduc-

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ted in the winter oilseed rape planting area across the Yangtze River Basin, with a wide range of rapeseed yields (179–4 470 kg ha^{-1}). The aims of this study were (i) to determine rapeseed yield response to N, P, and K fertilization across a large-scale region, (ii) to determine the nutrient uptake-yield relationship of winter oilseed rape, and (iii) to evaluate the nutrient efficiency of winter oilseed rape, under currently recommended fertilization rates in this region.

MATERIALS AND METHODS

Database

This study used a database from the Chinese National Project of Soil Testing and Fertilizer Recommendation, which included a total of 619 site-year experiments in the Yangtze River Basin of China from 2005 to 2010. The region experiences a subtropical monsoon climate typically with cold winters (from November to February) and hot summers (from July to September). An average annual temperature varies from 10.5 to 24.2 °C across the sites, and an annual precipitation is in the range of 700–1 900 mm. Table I shows some soil chemical properties (0–20 cm) across the 619 site-year experiments.

Experimental design

Fourteen fertilization treatments were designed in each site-year experiment, and four of those fertilization treatments were chosen for detailed analysis: (i) balanced application of N, P, and K fertilizers (NPK), (ii) application of P and K fertilizers (N omission treatment, –N), (iii) application of N and K fertilizers (P omission treatment, –P), and (iv) application of N and P fertilizers (P omission treatment, –K). Each experiment was treated as one replicate during the regional analysis. Adjacent 20-m^2 plots at each site were separated by a 0.5-m-wide plant-free border strip.

The amounts of N, P, and K fertilizers for winter oilseed rape in each field experiment were recommended by local agronomic technicians, based on previous experiments, and designed to achieve a high rapeseed yield in the locality. Thus, fertilization rates varied widely, with average rates of 187 ± 49 kg N ha^{-1} (ranging from 75 to 399 kg N ha^{-1}), 37 ± 12 kg P ha^{-1} (ranging from 10 to 92 kg P ha^{-1}) and 90 ± 42 kg K ha^{-1} (ranging from 15 to 249 kg K ha^{-1}) as urea (46% N), calcium superphosphate (5% P), and muriate of potash (50% K), respectively. For all experiments, P and K fertilizers were applied as basal fertilizers (*i.e.*, fertilization before sowing). Nitrogen fertilizer was applied in three portions, 60% before sowing, 20% in the over-wintering period, and 20% in the bud period. In addition, borax was applied at 15 kg ha^{-1} prior to sowing for all treatments to prevent boron deficiency.

In the Yangtze River Basin, winter oilseed rape is generally sown in September, transplanted in October and harvested in May of the following year. All experiments were carried out by local technicians using commercially available cultivars in local markets, while the control of weeds, diseases, and insect pests followed local agronomic practices.

Sampling and analysis

Soil samples were collected in all experiments prior to the start of sowing of winter oilseed rape. Composite soil samples (10 cores per site) were collected from the top 20 cm soil profile. The samples were air dried, and then crushed to pass through a 1-mm sieve prior to chemical analysis. Soil organic matter was determined by the chromic acid titration method (Walkley and Black, 1934); the alkaline hydrolysable N was determined by the alkali hydrolysis and diffusion method (Bao, 2000); available P was determined by the $NaHCO_3$ method (Olsen, 1954), and available K was determined by the NH_4OAc extraction and flame photometer method (Jackson, 1958). Soil pH was determined with a pH electrode at a soil:water ratio of 1:2.5 (Page, 1982).

When the winter oilseed rape was mature, aboveground parts of six plants were randomly selected as the samples for each treatment. Plants were separated into rapeseed and straw (*i.e.*, aboveground biomass except for rapeseed) to analyze N, P, and K uptake of rapeseed and straw. Plant samples were oven dried at 65 °C, ground to pass a 1-mm sieve, and digested separately with H_2SO_4-H_2O_2. Contents of plant N, P, and K were measured by the Kjeldahl method (Horwitz and

TABLE I

Some basic soil properties (0–20 cm) across 619 site-year experiments in the Yangtze River Basin

Parameter	Organic matter	Alkaline hydrolyzable N	Available P	Available K	pH
	g kg^{-1}	mg kg^{-1}			
Mean ± SD[a)]	25.6 ± 11.1	130.2 ± 47.3	15.3 ± 11.5	91.4 ± 46.1	6.4 ± 1.0
Range	3.7–82.0	22.0–315.0	1.0–72.6	11.0–338.0	4.0–8.5

[a)]Standard deviation.