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Responses of plant development, biomass and seed production of direct sown oilseed rape (*Brassica napus*) to nitrogen application at different stages in Yangtze River Basin

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ABSTRACT

Direct sown oilseed rape has been rapidly developed in recent years due to increasing shortage of labor force in the winter oilseed rape (*Brassica napus* L.) region of Yangtze River Basin. However, the appropriate nitrogen management of the crop has not yet been established, resulting in poor seed yield. Two experiments were conducted, including a pot trial to elucidate the N utilization in different growth periods under sufficient supplies of N and other nutrients, and a field experiment to study the effects of N application rates at different stages on plant development, biomass production, seed yield and N use efficiency of direct sown oilseed rape. The results showed that N applications at different stages extended the growth period of the crop. The vegetative growth was extended more than the reproductive growth by N applied at early stages. Nitrogen application promoted the plant growth center/s leading to high biomass accumulations in different periods. Higher pre-sowing N rates prolonged the fast biomass accumulation period and increased the fastest accumulation speed. The seed yield and NUE of the crop were improved by N applied prior to sowing and at the initiation of stem elongation. The results suggest that, relatively high N rate but not exceeding 135 kg N ha^{-1} applied at pre-sowing, 67.5–90 kg N ha^{-1} at the initiation of stem elongation, and appropriate rates depending on the seedling growth at 5-leaf stage were optimum N fertilizer strategies to achieve high production for the direct sown winter oilseed rape in Yangtze River Basin.

1. Introduction

China produces the largest amount of rapeseed, accounting for 21.0% of the total oilseed rape (*Brassica napus* L.) cultivated and 20.4% of the total rapeseed produced in the world in 2014–15 (USDA FAS, 2015). Yangtze River Basin is the largest oilseed rape production region with about 6.67 M ha of winter oilseed rape plantation annually, which is about 90% of total rapeseed production in China (Li et al., 2015). Hence, the sustainable production of oilseed rape in this region is of great importance to the edible oil supplies in China and worldwide. Transplantation has been conventionally used as a major establishment method for the crop in this region. However, the increasing labor shortage led to the decline of oilseed rape plantation in the past years, because of the intensive labor requirement for seedling transplantation (Wang et al., 2014). Alternatively, direct sowing method has been recently developed as a new establishment tool in this region. However, the yield performance of direct sown winter oilseed rape has been significantly lower than that of transplanted oilseed rape (Yuan et al., 2014). A study conducted by Wang et al. (2014) showed that a comparable yield to transplanted oilseed rape can be achieved if the direct sown oilseed rape grows under favorable conditions. Therefore, it is imperative to develop appropriate management strategies for direct sown winter oilseed rape in Yangtze River Basin.

Oilseed rape is a species with high nitrogen demand in *Brassica* genus (Barłóg and Grzebisz, 2004a), and N is the most important

Abbreviations: DAE, days after emergence; FAP, fast accumulation period; NUE, nitrogen use efficiency; N, nitrogen; P, phosphorus; K, potassium.

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among the growth-limiting factors that affect biomass production and its partitioning to seed production (Barłóg and Grzebisz, 2004b; Rathke et al., 2006; Brennan and Bolland, 2007). Optimal N application rate depends on multiple factors such as cultivar characteristics (Zhang et al., 2010), soil type and soil N availability (Barłóg and Grzebisz, 2004a), plant density (Rood and Major, 1984; Xie et al., 2013), and tillage method (Han et al., 2011). A wide range of N application rates from 150 to 270 kg N ha^{-1} has been recommended for transplanted oilseed rape in Yangtze River Basin (Li et al., 2011; Wang et al., 2011a; Yuan et al., 2014). Oilseed rape requires different N amounts at various stages, and an appropriate N application scheme is conducive to promoting both seed yield and NUE (Barłóg and Grzebisz, 2004a). Most researchers have focused more on the N impact on seedling growth because it is closely related to the establishment of the sink strength in winter oilseed rape (Major et al., 1978; Chapman et al., 1984); therefore, higher N rate is usually applied at early stages. For instance, Li et al. (2011) showed that high seed yield and NUE were attained under an application scheme of 60% N applied at pre-sowing, 20% N at over-winter stage and 20% at the initiation of stem elongation in transplanted oilseed rape of Yangtze River Basin.

Rape crops may undergo different developmental progress under various establishment methods, and correspondingly require different N managements (Schnier et al., 1990; Wang et al., 2014). Wang et al. (2014) indicated that direct sown oilseed rape showed weaker individual growth but more sensitivity to N deficiency and greater response to N application than transplanted oilseed rape. Han et al. (2011) reported similar findings and suggested that more N fertilizer should be applied for direct sown oilseed rape than for transplanted oilseed rape.

Oilseed rape is also characterized as a species with low N efficiency (Rathke et al., 2006). Excessive N application is not only unnecessary for increasing crop yield but also detrimental in NUE and environmental protection (Rahimizadeh et al., 2010; Tilman et al., 2011). Development of appropriate N management strategies for the crop requires a good understanding of its N demands at different growth stages; however, such information is scarce for direct sown winter oilseed rape in Yangtze River Basin (Xie et al., 2013). Moreover, most results for N application in oilseed rape have been obtained from studies focusing on the appropriate N rate under a fixed application scheme (Boelcke et al., 1991) or the appropriate scheme under a fixed N rate (Han et al., 2011). In this study, we aimed to study the N utilization at different stages under sufficient supplies of N and other nutrients using a pot trial, and the effects of N application rates at different stages on the plant development, biomass production, seed yield and NUE of direct sown oilseed rape using a field experiment. It is expected that findings from this study will help to develop appropriate N management strategies for direct sown oilseed rape in Yangtze River Basin.

2. Materials and methods

2.1. Experimental site and material

A pot and a field experiment were conducted on the experimental farm of Huazhong Agricultural University, Wuhan, China (30°37′N, 114°21′E, 27 m above sea level) in 2013–2014. The soil for the pot trial was from the same paddock of the field experiment, and was yellowish brown sandy loam that contained 5.2% clay (<0.002 mm), 27.1% silt (0.002–0.02 mm) and 67.7% sand (0.02–2 mm). The climate is typical in the northern subtropical zone in Yangtze River Basin, with mean annual temperature ranging from 15 °C to 18 °C, mean annual precipitation ≥1100 mm (30%–40% falling in the oilseed rape cropping season), and mean frost-free period of 230–300 days.

Table 1
Nitrogen (N) application rates (g N kg^{-1} soil) at various stages in pot trial. B, S, O and E denote N application at pre-sowing, 5-leaf, over-winter and the initiation of stem elongation, respectively.

Treatment	Pre-sowing	5-leaf	Over-winter	Initiation of stem elongation	Total
Control	0.0	0.0	0.0	0.0	0.0
B	0.10	0.0	0.0	0.0	0.10
BS	0.10	0.02	0.0	0.0	0.12
BSO	0.10	0.02	0.02	0.0	0.14
BSOE	0.10	0.02	0.02	0.06	0.20

The soil used in the pot trial contains 2.18% organic matter, 3.37 mg kg^{-1} of ammonium-N, 1.51 mg kg^{-1} of nitrate-N, 31.28 mg kg^{-1} of Olsen-P and 129.37 mg kg^{-1} of available-K, with pH of 5.75. The soil in field experiment within 0–20 cm had 1.23% organic matter, 2.45 mg kg^{-1} of ammonium-N, 1.10 mg kg^{-1} of nitrate-N, 8.27 mg kg^{-1} of Olsen-P, and 134.42 mg kg^{-1} of available-K with pH 5.71.

An oilseed rape cultivar that is commonly sown in Yangtze River Basin, viz., Huaza 9, was used as material. Seed of the cultivar was provided by the Oilseed Rape Laboratory of Huazhong Agricultural University.

2.2. Experimental set-up and management

2.2.1. Pot trial

Non-transparent plastic pots (25 cm in surface diameter and 33 cm in depth) with five small holes (1 cm in diameter) and a separate tray under the bottom to receive the leachate was used as incubators. Each pot contained 9 kg air-dried and sieved soil with 3% of water content. Prior to filling soil, two layers of filter paper were laid on the inside bottom of the pot to prevent soil outflow. Based on the common N application rate in pot trial for winter oilseed rape in this region (Song et al., 2007), four different N treatments were applied: (1) pre-sowing application only (B, basal fertilization); (2) pre-sowing + 5-leaf stage applications (BS); (3) pre-sowing + 5-leaf stage + over-winter (9-leaf stage) applications (BSO); and (4) pre-sowing + 5-leaf + over-winter + initiation of stem elongation applications (BSOE). None-N application throughout the whole growth season was used as a control. Therefore, there were a total of 5 treatments (Table 1). Twenty-four pots were planted for Treatment B and the control, and 20, 16 and 12 pots for Treatments BS, BSO and BSOE, respectively. A mixture of fertilizers including 0.1 g P_2O_5 kg^{-1}, 0.1 g K_2O kg^{-1} and 0.5 mg boron (B) kg^{-1} were applied to all treatments including the control, 0.1 g N kg^{-1} was mixed into the soil of all N treatments as basal fertilizer two days before sowing, and 0.04 g K_2O kg^{-1} was top-dressed at over-winter stage for all treatments. For the N and K topdressing, urea and potassium chloride were dissolved in water and applied to the soil around the plants.

Ten seeds were sown in each pot on 25 October 2013, seedlings were thinned to four at 2-leaf stage and then one healthy seedling kept in each pot at the 5-leaf stage prior to fertilizer application. All pots were arranged in a completely randomized design under a transparent rain-proof shelter. All pots were watered regularly and with the same volume of 1.2 L each time to ensure there was no moisture deficiency. The leachate in the tray under the pot was washed with small amount of tap water and returned to the pot next day to avoid nutrient loss from leakage. Plants were harvested on May 3, 2014.

2.2.2. Field experiment

The field experiment that included 3 subsets of treatments for various stages was designed using a randomized complete block (RCB) arrangement with 3 replicates. Based on the common N application rate (Tang and Guan, 2001; Han et al., 2011) and scheme