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Higher density planting benefits mechanical harvesting of rapeseed in the Yangtze River Basin of China

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ABSTRACT

Winter rapeseed is an important oilseed crop in the Yangtze River Basin. To optimize its cultivation in this area and improve its production efficiency, a split-plot experiment with various planting dates (25 September and 10 October), nitrogen applications (120, 240 and 360 kg ha^{-1}) and planting densities (3.0 × 10^5, 4.5 × 10^5 and 6.0 × 10^5 plants ha^{-1}) was performed to investigate their effects and interactions on the seed yield of rapeseed, its lodging index and weed occurrence in farmland. Our results indicated that (1) Delay in planting led to the decrease in the net photosynthetic rate (*Pn*) of leaf, nitrogen seed production efficiency (NUE), pod number per plant and yield, but aggravated weed occurrence. The increase in nitrogen fertilization resulted in reduced NUE, elevated *Pn* of leaves, improved pod number per plant and yield, and facilitated weed growth. The increase of planting density elevated NUE, reduced *Pn* and yield per plant because of the lowered number of pods per plant, but enhanced the population yield and substantially inhibited weed growth. (2) Delayed planting inhibited rapeseed growth, showing significant reductions in plant height, rhizome diameter, root dry weight, aboveground dry weight and root/shoot ratio, and resulted in lower snapping resistance but a higher lodging index. Although higher nitrogen application improved root dry weight, rhizome diameter and snapping resistance, it resulted in the increase of plant height and aboveground dry weight, which led to a reduced root/shoot ratio and a greater lodging index. The increase in planting density lowered the rhizome diameter, root dry weight and snapping resistance, significantly reduced the plant height and aboveground dry weight, hence increasing the root/shoot ratio, which further decreased the lodging index. A linear relationship was observed between the seed oil content and lodging index (2013–2014, R^2 = 0.3783**; 2014–2015, R^2 = 0.5641**). Oil content was reduced while the lodging index increased, indicating that lodging index was a key factor determining oil content under various planting dates, nitrogen amounts, densities and their interactions.

1. Introduction

Rapeseed is one of the four most important oil crops in the world. It is also the fifth largest crop in China and the country's most important source of edible vegetable oil, so the rapeseed production is of great importance for the security of the edible oil supply in China. Mechanized harvesting can reduce rapeseed production costs and raise production efficiency. However, mechanized harvesting of rapeseed in China is far behind the developed countries and, at present, the mechanized harvesting area accounts for only 30.8% of the total mechanized farming area. The main reason for this is that the low efficiency of mechanized harvesting and high harvesting loss rates have led to difficulty in the extension of mechanized harvesting. Severe lodging of rapeseed is a key factor resulted in the low mechanical harvesting rate (Kuai et al., 2016).

Sowing date is an important cultivation factor for rapeseed production. The Yangtze River Basin is the main producing area of rapeseed in China, and it is often planted in rotation with rice. Within rice–rapeseed rotation, the planting date of rapeseed can vary widely due to variation in harvesting time of rice. In most cases, the prolonged growth period and delayed harvesting of rice leads to a late planting date for rapeseed. Many studies have demonstrated that planting date affects the growth, yield and quality of rapeseed (Hocking and Stapper, 2001; Miralles et al., 2001; Ozer, 2003; Neely et al., 2015). Delayed planting usually inhibits rapeseed growth, shortens the pre-flowering period and lowers the leaf area index and harvest index (HI). It also

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leads to early maturation and decreased branch number, pod number per plant and thousand seed weight, hence resulting in low yield (Ozer, 2003). Hocking and Stapper (2001) showed that rapeseed planting in May and July resulted in 35 and 67% yield reduction, respectively, compared with April planting. Late planting also affects seed oil content. Kirkegaard et al. (2016) found that oil content was reduced by 0.5–1.5% with a one-week delay in planting.

Optimizing the nitrogen rate and plant density are important ways to increase yield of crops, and they also affect crop lodging (Kuai et al., 2016). Various amounts of nitrogen application and plant densities produce different population structures that change light interception and light utilization rates, and eventually affect population yield and lodging resistance. The increase in nitrogen application amount within a certain range can elevate the light utilization rate of a crop (Caviglia and Sadras, 2001) but reduce the nitrogen use efficiency. In addition, excessive application of nitrogen fertilizer can lead to vigorous plant growth and decreases in stem plumpness, which elevates the lodging risk (Crook and Ennos, 1995). The occurrence of lodging in a crop lowers the utility rate of light energy (Sheehy et al., 1977) followed by yield reduction, which impedes mechanized harvesting process. The population photosynthetic area index and the utilization rate of light energy can be enhanced with the increasing density within a certain range, and it can fully show the crop population effect to improve yield (Diepenbrock, 2000). In China, the planting density of rapeseed is usually 1.0×10^5–1.5×10^5 plants ha^{-1}, lower than the high densities used in European countries, and this leads to the relatively low yield (Angadi et al., 2003). Most studies have shown that higher densities lead to more severe lodging (Ling et al., 2007; Novacek et al., 2013); however, studies on rapeseed have demonstrated that increases in plant density can improve lodging resistance (Kuai et al., 2015).

Many studies have focused on the single- or two-factor effects of sowing time, nitrogen and plant density on biomass accumulation and yield of rapeseed, but few have addressed the impact of the three factors and their interactions on growth, yield and lodging of rapeseed. Therefore, we designed split-plot experiments with planting dates, nitrogen fertilizer and plant density to explore their effects on agronomic traits, yield, lodging index and weed occurrence. The objective of the present study is to elucidate the effects of planting date, amount of nitrogen fertilizer and plant density on the mechanized harvesting of rapeseed, to provide a theoretical basis for the establishment of cultivation practices for high yield, lodging resistance and use of mechanized harvesting of rapeseed in the Yangtze River Basin.

2. Materials and methods

2.1. Experiment location, soil condition and plant materials

The field experiments were carried out in the experimental base of Huazhong Agricultural University (30.52°N, 114.31°E) during 2013–2014 and 2014–2015. In both years, a previous crop of rice was harvested in September. The soil nutrient conditions were as follows: alkali hydrolyzable nitrogen of 83.26 mg kg^{-1}, available phosphorus of 11.50 mg kg^{-1} and available potassium of 135.12 mg kg^{-1} in 2013; and correspondingly 87.68, 14.79 and 144.50 mg kg^{-1} in 2014. *Brassica napus* hybrid Huayouza 62 was used as plant material, which was developed and provided by Huazhong Agricultural University.

2.2. Experimental design

A split-plot experiment was performed with two planting dates as the main plot, 25 September (proper sowing: SWI) and 20 October (late planting: SWII). Three nitrogen application amounts, 120, 240 and 360 kg ha^{-1} (N120, N240 and N360, respectively), served as the split plots; and three densities of 3.0×10^5, 4.5×15^5 and 6.0×10^5 plants ha^{-1} (D1–D3, respectively) served as split-split plots. There were three replicates, and plots were 10 m × 2 m. Urea with nitrogen content of 46.7% was used as the nitrogen source, and applied in the ratio of 6:2:2 for basal fertilizer, fertilizer for seed bed and flower fertilizer. The amounts of phosphorus (P_2O_5) and potassium (K_2O) fertilizer were 150 kg ha^{-1} each, provided by 12% calcium superphosphate and 60% potassium chloride. The dosage of boron (B) was 7.5 kg ha^{-1}, and P_2O_5, K_2O and B fertilizer were applied only once as basal fertilizer. The seeds were sown on 25 September and 20 October, and the final thinning of seedlings was carried out at 3–5 leaf stage.

2.3. Measured items and method

2.3.1. Yield and its components

Plots were harvested when approximately two-thirds of the seed was brown. Ten plants per plot were randomly sampled and slowly uprooted, and the taproot and large lateral roots retained. Next, the yield components were determined: pod number per plant, seed number per pod and thousand seed weight. The seed yield per plant was also measured.

Plant height was the distance from cotyledon nodes to the top of the plant. The aboveground fresh weight was the weight above the cotyledon nodes, which was fixed at 105 °C followed by drying at 80 °C to obtain the aboveground dry weight. After grinding the sample, the nitrogen content of each part was determined by the Kjeldahl method. The harvesting index (HI) = yield per plant/aboveground dry weight. Seed yield per unit nitrogen production was obtained by dividing seed yield by total nitrogen uptake at maturity stage (without root system), which is the nitrogen seed production efficiency (NUE).

2.3.2. Lodging-related indicators

Ten plants were selected from each plot at the mature stage, and the height of the first effective branch was measured. The snapping resistance of the stem above the first branch was determined using a stem strength meter YYD-1 (Tuopu Instrument Co. Ltd., Zhejiang, China). The lodging index was then calculated according to Kuai et al. (2016):

Lodging index (cm g g^{-1}) = height (cm) × fresh weight (g)/snapping resistance (g)

where the height and fresh weight were measured from the tested stem to the top of plants and the snapping resistance was for the corresponding stem section.

2.3.3. Net photosynthetic rate (Pn)

Nine rapeseed plants were selected from each treatment, and the gas exchange parameters of their functional leaves (the fourth fully expanded leaves from top to bottom) were measured in the field using a LI-6400XT Portable Photosynthetic System, equipped with red and blue light source leaf chamber (Li-COR Inc., Lincoln, NE, USA). The measurement time was 9:00–11:30 am with the carbon dioxide concentration set to 400 μmol mol^{-1}, light intensity of 1200 μmol m^{-2} s^{-1}, leaf chamber temperature of 20 °C, air relative humidity of 60% and gas flow rate of 500 mol s^{-1}. The measurements were performed after 20–30 min of light activation, and the *Pn* determined when the instrument was stable (requiring 2–3 min).

2.3.4. Weed occurrence

The number and biomass of weeds were investigated at the maturity stage of rapeseed, according to Zuo et al. (2017). A sample of 1 m^2 was selected to determine weed number. The weeds were then cut at 1 cm aboveground, and the fresh samples were collected to measure biomass by fixing at 105 °C and drying to constant weight at 60 °C. The weed number and the biomass per hectare were calculated. Three replicates were measured for each treatment.