Field Crops Research 172 (2015) 42–52

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Effect of wide–narrow row arrangement and plant density on yield and radiation use efficiency of mechanized direct-seeded canola in Central China

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ARTICLE INFO

Article history:
Received 10 June 2014
Received in revised form 3 December 2014
Accepted 4 December 2014

Keywords:
Canola
Wide–narrow row arrangement
Plant density
Radiation use efficiency
Yield

ABSTRACT

Direct-seeding is an effective canola cultivation method for saving production costs compared with transplanting seedling. The aim of this study was to understand the effects of wide–narrow row arrangement and of plant density on canola yield as well as its related parameters under mechanized direct-seeding farming system. A 3-year field experiment was conducted to evaluate the influences of different row spacing arrangements and plant densities on seed yield and canopy radiation use efficiency in three growing seasons (2009–2012). Treatments included two levels of plant densities (15 and 45 plants m^{-2}), in combination with six levels of row spacing arrangements (three uniform row spacings and three wide–narrow row spacings). Results showed that the wide–narrow row arrangements of "20 + 20 + 40" cm (S6) increased average seed yields by 10% above the conventional 30 cm spacing (S2) in three experimental seasons. The treatment of "17.5 + 17.5 + 17.5 + 35 + 17.5 + 17.5 + 17.5 + 60" cm (S4) was exclusively designed as a wide–narrow row plantation for purpose of mechanization management, but yield of S4 did not decrease compared with S2. Meanwhile, plant density of 45 plants m^{-2} produced more yield than that of 15 plants m^{-2} by 4% in 2009–2010, by 7% in 2010–2011 and by 10% in 2011–2012. More effective pods per plant (about 17%) were achieved in wide–narrow row arrangements comparing with uniform ones, which were further supported by higher leaf area index and radiation use efficiency. S6 had 10–28% greater radiation use efficiency than S2 in three seasons. Hence an appropriate wide–narrow row arrangement could not only intercept more favorable photosynthetic active radiation, but also led to record substantially higher above-ground biomass accumulation (22%–33%) and more seed number per m^2 (approximately 28%) compared with S2. Based on yield performance, the combination of 45 plants m^{-2} and S6 is the optimal scheme for canola production, and S4 is a promising alternative for planting mechanization under direct-seeding cropping system in Central China.

1. Introduction

Direct seeding of canola refers to the process of establishing a crop from seeds sown in the field rather than transplanting seedlings from the nursery (Hu and Ding, 2008). In Europe, mechanized direct-seeding is a common cultivation practice for canola sowing (Momoh and Zhou, 2001), while in China, seedling transplanting is a traditional and still dominant method of canola establishment (Yin and Wang, 2012). Transplanting seedlings into fields is labor intensive, however, labor availability is increasingly reduced in China mainly due to the migration of rural labors into cities (Peng et al., 2009; Wang, 2010). Therefore, there is a need to seek an alternative system for canola production. Mechanized direct-seeding, characterized by its easy-handling and labor-saving privileges, can be of an effective technology to replace seedling transplanting. Factually, mechanized direct-seeding has increasingly been practiced in major canola-producing regions of China. However, yield decline has been observed as for canola production in this shift process (Hu and Ding, 2008). Meanwhile, previous studies also revealed that canola yield had been widely affected by agronomic practices such as manipulation of row arrangements and plant density (Leach et al., 1999; Diepenbrock, 2000; Momoh and Zhou, 2001; Bilgili et al., 2003; Johnson and Hanson, 2003; Rathke et al., 2006). Thus adjusting row spacing arrangement is presumably another important agronomic practice for increasing yield.

Canola yield of winter canola increased with narrowing row spacing from 30 to 15 cm or 35 to 17.5 cm (Morrison et al., 1990;

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http://dx.doi.org/10.1016/j.fcr.2014.12.005
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Sincik et al., 2010). But the magnitude of yield gain was slight, varied or inconsistent with narrowing row spacing for winter canola (May et al., 1993; Johnson and Hanson, 2003; Stenberg et al., 2013). Shanhin and Valiollah (2009) showed that seed yield of winter canola grown at 12 cm row-spacing was lower than that at 24 cm. What is more, much narrower row spacing would bring more obstacles for management practices such as post-emergence herbicide and fertilizer application (Balkcom et al., 2010). On the other hand, much-documented is that wider row-spacing almost without exception leads to reduced crop stands per unit area (Hu and Ding, 2008), as is the case of canola plantation. To solve this problem, wide–narrow row spacing might be a good solution if integrating the advantages of both narrow row spacing and wide row spacing alone. As a matter of fact, some researchers have reported comparative advantages in wide–narrow row arrangements for corn and wheat (Li et al., 2008; Liu et al., 2011).

It is well known that plant density could influence seed yield and yield components of winter canola (Diepenbrock, 2000). Increasing plant density usually leads to greater seed yield until an optimum density is reached. In Europe, the required plant density is about 60–70 plants m^{-2} for hybrids canola (Rathke et al., 2006). While average seed yield might be achieved under a wide range of plant density from 8 to 90 plants m^{-2} (Mendham et al., 1981). In China, the common plant density is about 30 plants m^{-2} for hybrid rapeseed (Momoh and Zhou, 2001; Zhang et al., 2012; Yang et al., 2013). With the rapid shift from transplanting system to direct seeding for canola production, the optimum plant density should be re-evaluated for current agronomic management and farming system.

Determining radiation use efficiency (RUE) is a useful approach to understand the differences in canola growth and yield formation under different cultivation practices (Diepenbrock, 2000). Practices favoring RUE improvement can increase crop yield (Murchie et al., 2009). Large variability of canola RUE has been observed from 1 to 4 g MJ^{-1} in different growth and development stages (Habekotte, 1997; Leach et al., 1999). From emergence to maturity of winter canola, RUE was 1.76–2.63 g MJ^{-1} in different nitrogen level (Justes et al., 2000). It seems that the mean RUE over the whole canola cycle would be significantly affected by plant density and row spacing and other varied agriculture management practices (Hamzei and Soltani, 2012).

There have been a number of studies that investigated the effects of plant density and uniform row spacing on canola physiology and production, while few studies have investigated the effect of wide–narrow row arrangement on winter canola, especially on crop RUE. The aims of this study are: firstly, to evaluate effects of wide–narrow row arrangement and plant density on seed yield and yield components of canola; secondly, to compare LAI and RUE responses to wide–narrow row spacings and uniform ones; and thirdly, to determine optimum row arrangements for mechanized direct-seeding canola production in the Central China.

2. Materials and methods

2.1. Experimental site

Field experiments were conducted at the experimental farm of Huazhong Agricultural University, Wuhan, China (114°22′E, 30°29′N) from 2009 to 2012. Soil properties about 30 cm deep of the field were: pH 6.3, 21.7 g organic matter kg^{-1}, 10.9 mg NO_3–N kg^{-1}, 4.6 mg NH_4–N kg^{-1}, 18.1 mg Olsen-P kg^{-1}, and 155.0 mg NH_4OAc-extractable K kg^{-1}. Meteorological data and daily photosynthetically active radiation (PAR) were recorded during canola growing period at a local weather station adjacent to the experimental site.

Table 1
Inter row spacing obtained based on applied row spacing arrangement and plant density for each treatment.

Row spacing arrangement	Plant density (plants m^{-2})	Inter row spacing (cm)	Row number for each plot
S1	15	32.0	20
S2	15	20.8	13
S3	15	16.0	10
S4	15	25.6	16
S5	15	22.4	14
S6	15	24.0	15
S1	45	10.7	20
S2	45	6.9	13
S3	45	5.3	10
S4	45	8.5	16
S5	45	7.5	14
S6	45	8.0	15

2.2. Experimental design

Huayouza 9 (HZ9), a popular winter canola hybrid cultivar with a reputation for high seed yield in Central China, was used in the experiment. Field experiment for each season was arranged on a split-plot design with plant density as the main plot and row spacing arrangement as the subplot. The area of each plot was 20 m^2 (4 m × 5 m), and four replications were conducted in each season. Two plant densities were used: 15 and 45 plants m^{-2}. Each plant density had six row spacing arrangements: 3 uniform row spacings, i.e. 20 cm (S1), 30 cm (S2) and 40 cm (S3); and 3 wide–narrow row arrangements: i.e. “17.5 + 17.5 + 17.5 + 35 + 17.5 + 17.5 + 17.5 + 60” cm (S4), “20 + 40” cm (S5), and “20 + 20 + 40” cm (S6). The six row arrangements are illustrated in Fig. 1, while inter row spacings and plant densities varied in each plot (Table 1). S2, an arrangement commonly applied for planting oil-seed rape in China, was designed to provide control treatment, while S4 was designed to represent wide–narrow row arrangement to meet mechanization requirements of post-emergence field managements in Central China.

Seeds were directly sown in the prepared rows for each plot by hand on October 8, 2009, October 5, 2010 and October 14, 2011. Seedlings were thinned by hand after emergence and plant densities were finally determined at 5th leaf stage according to record. Fertilizers used were urea for N, single superphosphate for P, potassium chlorid for K and borax for B, and doses were 180 kg N ha^{-1}, 90 kg P_2O_5 ha^{-1}, 150 kg K ha^{-1} and 7.5 kg B ha^{-1}, respectively. N was split-applied: 90 kg N ha^{-1} at basal and 90 kg N ha^{-1} at bud initiation. P, K and B were all applied as base fertilizer one day before sowing. Pests, diseases, birds, and weeds were controlled as required to avoid yield loss.

2.3. Measurement, sampling and harvest

Canopy radiation interception was measured using SunScan Canopy Analysis System (Delta-T Devices Ltd., UK) at a 7–10 day intervals from 5 leaf stage to maturity. To measure the transmitted radiation, the 1-m probe was placed perpendicular to rows near soil surface for each plot. Another sensor (model BF5) was located outside the canopy for measurement of incident photosynthetically active radiation (PAR) (Hamzei and Soltani, 2012; Robles et al., 2012). Measuring was completed within 1.5 h of solar noon on clear days. Six positions were randomly selected and marked in each plot for measuring canopy radiation interception, and six measurements were recorded in each plot.

Canopy radiation interception was calculated as the percentage of incoming radiation intensity that was intercepted by the canopy [100 × (incoming radiation intensity − radiation intensity