Europ. J. Agronomy 74 (2016) 185–192

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Effect of panicle nitrogen on grain filling characteristics of high-yielding rice cultivars

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ARTICLE INFO

Article history:
Received 1 March 2015
Received in revised form 4 November 2015
Accepted 5 November 2015
Available online 4 January 2016

Keywords:
Rice varieties
Different genotypes
Panicle nitrogen fertilizer
Grain filling characteristics

ABSTRACT

The effects of four levels of panicle nitrogen fertilizer on the grain filling characteristics of three rice (*Oryza sativa* L.) varieties (super *japonica* rice Ningjing 3, three-line *japonica* hybrid rice Changyou 3 and three-line *indica–japonica* hybrid rice Yongyou 12) were analyzed. The results showed that difference in time of maximum filling rate (T_{max}) was the smallest between the superior and inferior spikelets of Ningjing 3, bigger between those of Changyou 3, the biggest between those of Yongyou 12. Ningjing 3 was of the synchronous grain-filling type, Yongyou 12 the asynchronous type, and the Changyou 3 the medium type. The grain filling rate, the initial filling power (R_0), the maximum filling rate (G_{max}), and the average filling rate (G) of the superior and inferior spikelets of the three varieties under the treatment of panicle N with the amount of 120 kg ha^{-1} (middle panicle N, shortened as NM) treatment were higher than those of other treatments. NM treatment led to the highest increase in grain weight at the middle stage of filling for all the three varieties. The treatment shortened the early and late stages of grain filling, but extended the middle stage when the filling rate was the highest. However, the middle stage of grain filling of Changyou 3 and Yongyou 12 was much more extended than that of Ningjing 3, indicating a better effect of N on hybrid rice varieties.

1. Introduction

Rice is the most important crop in China, accounting for about one-third of the total grain production of the country each year and contributing to China's food security (Xie, 2007). When rice supply is sufficient, people demand for rice of better quality, which prompts researchers to make incessant effort to increase production of *japonica* rice varieties in the country. Currently, there two popular ways of research in this regard: to employ the advantage of the suitable light and temperature resources for double-cropping in southern China to grow *japonica* rice varieties instead of *indica* varieties, and to breed super *japonica* rice varieties with greater productive potential (FAO, 2004; Zhang et al., 2013). The current popular methods are to breed *japonica* male sterile lines of nuclear–cytoplasmic interaction and restorer lines of *japonica* male sterile lines with strong recovery, and to cross-fertilize super *indica* and *japonica* varieties. As a result, a number of super hybrid *japonica* rice varieties have been obtained (Jiang et al., 2014). However, these rice varieties have not produced the expected yield, because of insufficient filling of the grains at the lower part of the panicle (Kato et al., 2007; Cheng et al., 2007; Peng et al., 2008), for which the researches have been carried out, dealing with temporal and spatial variation in endogenous hormones of superior and inferior spikelets (Yang et al., 2001, 2002a), sucrose-starch metabolism (Nakamura et al., 1989; Nakamura and Yuki, 1992), differential gene expression of superior and inferior spikelets (Lin et al., 2011), metabolism of starch in the endosperm (Huang and Zou, 2004) and differences in grain-filling patterns between erect-panicle and curved-panicle *japonica* rice cultivars (Li et al., 2013). At the same time, the application of N fertilizer, a common means to increase production, has been investigated, applying different amounts of fertilizer in different stages of plant growth (Xu et al., 2009; Yuan et al., 2007; Zhang et al., 2009; Liu et al., 2012a,b). However, no information is available, to our knowledge, on the effect of panicle N fertilizer on the grain filling of rice crop. Proper administration of panicle N is crucial in rice production (Yang et al., 2004; Wu et al., 2007).

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http://dx.doi.org/10.1016/j.eja.2015.11.006
1161-0301/

Therefore, this was to investigate differences in filling characteristics between the different genotypes of *japonica* rice varieties under different N treatments in different stages of panicle development. The results would provide basis and reference for breeding quality and high yield rice varieties.

2. Materials and methods

2.1. Materials

The rice varieties of Ningjing 3, Changyou 3 and Yongyou 12 were used as tested materials, and the conventional super *japonica* rice variety of Ningjing 3 was used as control growing for about 150 days and producing about 120 grains per panilce. Changyou 3 was a three-line *japonica* hybrid rice, growing for about 160 days and producing about 160 grains per panicle. Yongyou 12 was a three-line *indica–japonica* hybrid super rice, growing for about 170 days and bearing about 300 grains per panicle.

The rice varieties of Ningjing 3, Changyou 3 and Yongyou 12 were used as tested materials, and Ningjing 3 was conventional super *japonica* rice, growing for about 150 days and the grain numbers were about 120 grains per panicle. Changyou 3 was a three-line *japonica* hybrid rice, growing for about 160 days and the grain numbers were about 160 grains per panicle. Yongyou 12 was a three-line *indica-japonica* hybrid super rice, growing for about 170 days and the grain numbers were about 300 grains per panicle.

2.2. Experimental designs

This experiment was conducted in a period from 2012 to 2013 in the Baolin Farm, Danyang County, Jiangsu Province, China (119°28′ E, 31°54′ N). The previous crop was wheat. The testing soil was yellow clay. The soil fertility foundation was man-made as follows: 0–20 cm topsoil soil (naturally dry) containing 1.26 g kg^{-1} of N, 102.86, 13.15 and 109.14 mg kg^{-1} of available N, P and K and 20.76 g kg^{-1} of organic matter. Rice seeds were pre-germinated and sowed in late May. In late June, when seedlings were 24-day-old, they were mechanical transplanted to rice tested field. Test was a complete randomized block design by mechanical transplanting at an average spacing of 13.3 × 30 cm, three seedlings per hole for conventional *japonica* rice, two seedlings per hole for hybrid *japonica* rice. The tested areas were randomly positioned of 66 m^2 each, in three replicates; and the plots were separated by an alley 0.5 m wide with plastic film inserted into the soil to a depth of 60 cm to form a barrier. The amount of basal and tiller N was administered as 165 kg ha^{-1}. Panicle N was administered at four levels of 0, 60, 120 and 180 kg ha^{-1}, representing N0(zero panicle N), NL(low panicle N), NM and NH(high panicle N), respectively. Panicle N was applied as spikelet-promoting at panicle initiation stage which means the forth leaf from top stretching and spikelet-sustaining at the 2nd leaf from top stretching, both of which were used of equal amount. P_2O_5 was used as basal fertilizer and the application amount was 135 kg ha^{-1}. K_2O was half basal fertilizer and half spikelet-promoting fertilizer, and the application was150 kg ha^{-1}. The other measures of field management were performed with reference to the usual measures for the local high yielding. The weather conditions during the test are presented in Table 1, with the meteorological data collected by the local field weather stations.

2.3. Sampling and determination of grain filling

According to the method by Zhu et al. (1988), plants heading and flowering on the same date were selected and marked as single stems with similar growth, and 300 single stems were marked per area. The single plants were sampled in the period from flowering to 50 days after flowering, and 20 samples were collected every 5 days. Each panicle was divided into two parts: superior and inferior. The corresponding superior grains produced on the first 2 days after flowering, and the inferior grains produced on the last 2 days, were harvested, dried in an oven at 105 °C for 30 min, and then at 80 °C till constant weight. Richards equation (Richards, 1959; Zhang et al., 2011a) was used to fit the process of grain filling, and the basic parameters of the tested rice varieties were measured as follows:

$$W = \frac{A}{(1+\mathrm{Be}^{-\mathrm{Kt}})^{\frac{1}{N}}} \tag{1}$$

where W was the weight (mg), A the final grain weight (mg), t the days after flowering. B, K and N were the parameters set by the regression equation. R^2 was the coefficient of the fitfulness of the equation. The derivation of the Eq. (1) is the growth rate Eq. (2).

$$G = \frac{\mathrm{AKBe}^{-\mathrm{Kt}}}{\mathrm{N}(1+\mathrm{Be}^{-\mathrm{Kt}})^{\frac{(\mathrm{N}+1)}{\mathrm{N}}}} \tag{2}$$

In analysis, we adopted the following secondary parameters to describe the filling characteristics: R_0, $T_{\max}$ and $G_{\max}$; G and active filling date (D). The formulas were as follows:

$$R_0 = \frac{K}{N} \tag{3}$$

$$T_{\max} = \frac{\ln B - \ln N}{K} \tag{4}$$

Put the $T_{\max}$ into (2), and we could get the $G_{\max}$

$$G = \frac{AK}{2(N+2)} \tag{5}$$

$$D = \frac{2(N+2)}{K} \tag{6}$$

In order to divide the filling process into the early, middle, and late stages, two inflection points t_1 and t_2 were calculated with the growth rate Eq. (2); and when the grain weight reached 99% A, the filling was assumed to end, at which the time point was represented as t_3.

$$t_1 = \frac{-1\mathrm{n}\frac{N^2+3N+N\sqrt{N^2+6\mathrm{N}+5}}{2B}}{K} \tag{7}$$

$$t_2 = \frac{-1\mathrm{n}\frac{N^2+3N+N\sqrt{N^2+6\mathrm{N}+5}}{2B}}{K} \tag{8}$$

Table 1
Meteorological condition during the experiment.

Meteorological element	Year	Month						Average
		5	6	7	8	9	10	
Solar radiation(kJ cm^{-2})	2012	48.9	40.3	45.2	38.2	38.5	32.7	40.6
	2013	41.6	30.4	40.4	30.9	33.1	30.1	34.4
Mean temperature (°C)	2012	21.42	25.59	29.37	28.05	21.94	17.63	24
	2013	21.34	24.49	30.78	30.57	23.64	17.58	24.73