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Quantification of border effect on grain yield measurement of hybrid rice

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ABSTRACT

A border effect and yield overestimation due to a border effect have been studied for rice plants grown in small plots with the square geometry of transplanting. The objectives of this study were to measure the border effect of a plot transplanted in rectangular geometry with wide and narrow hill spacing and to quantify the effects of plot size and shape on yield overestimation due to a border effect. Two hybrid rice varieties (Zheyou 3 and II-you 838) were grown in a farmer's field with a hill spacing of 0.133 m × 0.267 m in 2011 in Hubei province, China. Grain yield and yield components were measured for outmost row, second and third outmost rows, and center rows. A significant border effect on grain yield was observed in the outmost row, but not in the second and third outmost rows in comparison with the center rows for both varieties. Higher biomass production, more panicles per m^2 and spikelets per panicle, and higher grain-filling percentage were responsible for the border effect. A larger border effect was observed on sides with wide hill spacing than with narrow hill spacing (142% vs. 62%). An equation was developed to calculate yield overestimation by considering the border effect of sides with wide and narrow hill spacing separately. According to this equation, minimum yield overestimation rate due to a border effect was 2.7% for a plot with an area of 1 mu (1 mu = 1/15 ha). Yield overestimation would be substantially higher for a plot with more rectangular shape and smaller plot size.

1. Introduction

A border effect can be defined as the difference in the performance between external plants and internal plants in a plot (e Silva et al., 2004; Gomez and De Datta, 1971). A border effect usually occurs when unplanted space is left between adjacent plots (unplanted borders) and adjacent plots are planted with different varieties or have different fertilizer treatments (plant competition) (Gomez, 1972; Gomez and De Datta, 1971). To facilitate field management, permit combine harvesting, and prevent mixing of seed during harvest, it is usually better to keep a space between adjacent plots in experiments (May and Morrison, 1986). In this circumstance, a border effect is caused by unplanted space.

A significant border effect due to unplanted space was reported in rice, maize, wheat, and soybeans (Gomez and De Datta, 1971; Li et al., 2000; Teng et al., 2008; Wang et al., 2012). Gomez and De Datta (1971) analyzed eight rice yield trials and reported that the increase in grain yield of the border rows over the center rows ranged from 63% to 159%, with an average of 116%. Liu et al. (2006) also reported a border effect of 9.9–51.4% in 24 rice varieties. The yield advantage of the border row was mainly attributed to more solar energy, good ventilation, and less competition for nutrients, which resulted in more panicles, higher biomass production, and consequently higher grain yields (Gomez and De Datta, 1971; Malabuyoc and Escuro, 1966; Sato and Takahashi, 1983; Wu and Shen, 1991).

Variety and hill spacing have a significant effect on the magnitude of the border effect. Some studies revealed that rice varieties with large panicles and strong tillering ability tended to show a greater border effect (Chen et al., 2006; Wu and Shen, 1991; Zhang et al., 2009). Furthermore, rice varieties with large panicles and strong tillering ability were suggested to be transplanted in rectangular geometry with wide and narrow hill spacing in order to maximize grain yield (Liu et al., 2006; Zhang et al., 2009). Transplanting with rectangular geometry is a common practice in China because most rice farmers grow high-yielding rice varieties with large panicles and strong tillering ability such as hybrid and super hybrid rice varieties. It is expected that the border effect for plants on sides with wide hill spacing will be higher than for plants on sides with narrow hill spacing.

In order to accurately estimate the grain yield, and substantially minimize the extraneous effects caused by a border effect, it was recommended to discard at least the outmost row for crop yield measurement (Hartwig et al., 1951; Hulbert and Remsberg, 1927;

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Malabuyoc and Escuro, 1966; Miller and Mountier, 1955). However, it is hardly applicable to remove border rows when a large number of breeding lines or new varieties is evaluated for grain yield in a small size of experimental plots because this is labor intensive and time consuming (May and Morrison, 1986; Romani et al., 1993). Furthermore, yield evaluation of elite rice varieties is commonly based on a crop cut of an entire plot with a size of around 1 mu (1 mu = 1/15 ha) in China. In these cases, a border effect will cause an overestimation of grain yield.

The magnitude of yield overestimation due to a border effect is influenced by the size and shape of the plot. In previous studies, equations have been developed to calculate yield overestimation rate due to a border effect (Gong and Wen, 1995; Li et al., 2000; Wang and He, 1999; Wu and Shen, 1991). In the equation of Wu and Shen (1991), plot size, length/width ratio, row spacing, and hill spacing within a row were included in calculating yield overestimation rate due to a border effect. They used the same value of border effect for plants on sides with wide and narrow hill spacing. For square geometry of transplanting, the border effect of each side may not be very different. For rectangular geometry of transplanting, however, the border effect of sides with wide hill spacing could be substantially higher than that with narrow hill spacing. The objectives of this study were to (1) quantify the difference in border effect between sides with wide and narrow hill spacing for a plot transplanted in rectangular geometry, (2) develop an equation for determining yield overestimation rate by considering the border effect of sides with wide and narrow hill spacing separately, and (3) quantify the effects of plot size and shape on yield overestimation due to a border effect. The main focus of this study was to quantify the contribution of border effect to yield overestimation for hybrid rice transplanted in rectangular geometry.

2. Materials and methods

A field experiment was conducted in farmers' fields at Zhangbang village, Wuxue county (29°51′N, 115°53′E), Hubei province, China, during the rice-growing season from May to October in 2011. Average solar radiation during this period was 15.7 MJ m^{-2} day^{-1}. The soil in these fields has the following properties: pH 5.6, 31.1 g kg^{-1} organic matter, 169.7 mg kg^{-1} alkali hydrolysable N, 17.2 mg kg^{-1} Olsen-P, and 66.2 mg kg^{-1} exchangeable K. Two indica hybrid rice varieties (Zheyou 3 and II-you 838) were used for the experiment. Zheyou 3 is a two-line hybrid newly developed by Zhejiang University. II-you 838 is a three-line hybrid developed by the Sichuan Institute of Nuclear Technology Application. II-you 838 has been recently used as a check variety in varietal trials in China.

Pre-germinated seeds were sown in a seedbed on 27 May. Seedlings were transplanted on 26 June at a hill spacing of 0.133 m × 0.267 m with 2 seedlings per hill. The west and east sides had a hill spacing of 0.133 m, and the north and south sides had a hill spacing of 0.267 m (Fig. 1). The plot for Zheyou 3 was 23.3 m along the west–east direction and 22.8 m along the north–south direction. The plot for II-you 838 was 21.7 m along the west–east direction and 32.8 m along the north–south direction. Phosphorus in the form of calcium superphosphate (40 kg P ha^{-1}) and zinc in the form of zinc sulfate heptahydrate (5 kg Zn ha^{-1}) were applied and incorporated in the field 1 day before transplanting. Potassium in the form of potassium chloride (112 kg K ha^{-1}) was split equally at basal and panicle initiation. Nitrogen in the form of urea (135 kg N ha^{-1}) was split-applied: 40% at basal, 25% at mid-tillering, and 35% at panicle initiation. The field was kept at 5–10-cm water depth from 3 days after transplanting to 7 days before maturity. Pests, diseases, birds, and weeds were intensively controlled to avoid yield losses. Other crop management practices followed the local recommendation to achieve high grain yield.

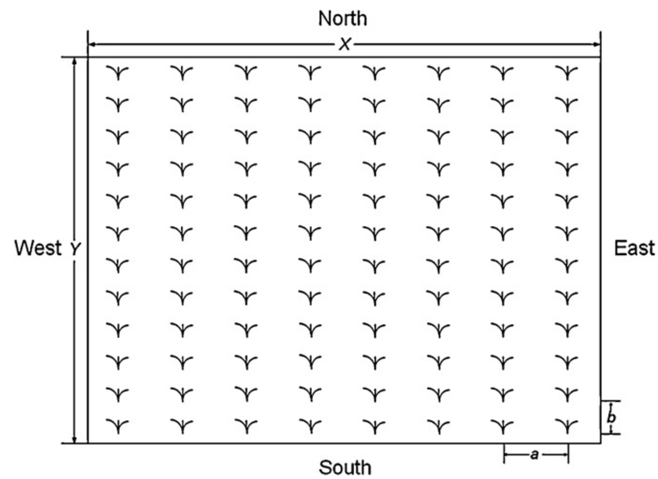

Fig. 1. A diagram showing the length (*X*) and width (*Y*) of the plot, hill spacing on north and south sides (*a*), and hill spacing on west and east sides (*b*).

At maturity, four 12-hill samples were taken from the outermost row (R1), second outermost row (R2), and third outermost row (R3) on each of the four sides (i.e. north, south, west, and east sides). In addition, four 12-hill samples were taken in the middle of the plot to estimate the grain yield of the center rows (CR). Panicle number was recorded from those 12 hills. Plant samples were separated into straw and panicles. The panicles were threshed by hand, and the spikelets were separated into filled and unfilled spikelets by submerging them in tap water. All the straw, rachis, and filled and unfilled spikelets were oven-dried at 70 °C to constant weight to determine the dry weight. Aboveground total biomass was the total dry weight of straw, rachis, and filled and unfilled spikelets. Spikelets per panicle, grain-filling percentage, and 1000-grain weight were calculated. Grain yield in each row was adjusted to the standard moisture content of 0.14 g H_2O g^{-1} fresh weight and expressed as grain yield per hectare. The border effect (*B*) was calculated as follows:

$$B = \frac{\text{Grain yield of border row} - \text{Grain yield of center rows}}{\text{Grain yield of center rows}} \times 100 \quad (1)$$

The mean and standard deviation were calculated using the values of four subsamples for the three border rows on each side and center rows separately. The border effect, hill spacing, and length and width of a plot were included in developing an equation for calculating yield overestimation by considering the border effect of sides with wide and narrow hill spacing separately.

3. Results

3.1. Border effect on yield and yield attributes

The grain yield of R1 was higher than that of R2, R3, and CR on the four sides for both varieties (Fig. 2). The grain yield of R2 and R3 was inconsistently different from that of CR. For R1, sides with wide hill spacing (north and south sides) produced grain yield of 20.5–26.7 t ha^{-1}, while sides with narrow hill spacing (west and east sides) produced grain yield of 15.4–17.7 t ha^{-1}. For R2, the grain yield of sides with wide hill spacing was 24% higher than that of sides with narrow hill spacing. There was a small and inconsistent difference in grain yield between sides with wide and narrow hill spacing in R3. In the center rows, Zheyou 3 and II-you 838 produced grain yield of 9.7 and 10.5 t ha^{-1}, respectively. In border rows, there was also an insignificant difference in grain yield between the