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Original research article

Photosynthesis and Transpiration Rates of Rice Cultivated Under the System of Rice Intensification and the Effects on Growth and Yield

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ABSTRACT

The system of rice intensification (SRI) crop management method has been reported by many authors to significantly increase rice yield with lower inputs, but physiological bases of yielding improvement have not been studied. In this research we assessed some physiological parameters and the mechanism of rice yield improvement of rice plants under SRI cultivation method during both vegetative and generative phases compared to conventional rice cultivation methods. We measured photosynthetic rate, transpiration rate, leaf temperature, chlorophyll content, N and P uptake, plant growth parameters and yield for those comparison. SRI methods significantly increased both vegetative and reproductive (generative) parameters of rice plants compared to conventional cultivation methods. Photosynthetic rate, chlorophyll content, N and P uptake under SRI cultivation were significantly higher compared to those of the conventional rice cultivation, but no differences were found in transpiration rate and leaf temperature. With SRI method, plants in their generative phase (especially in the grain-filling phase) had the highest photosynthetic and the lowest transpiration rates. Grain yield under SRI method was significantly higher (ca. 24%) than that of conventional method.

1. Introduction

The methodology of rice cultivation practice known as the system of rice intensification (SRI) is an innovation in agriculture that is still assessed continually, but its concepts and practices have been shown to increase rice productivity and farmers' incomes while reducing their need for water and other inputs. SRI method is focus on improving the growing environment of rice plants, above and below ground, by improving the management of plants, soil, water and nutrients, to stimulate the growth of bigger and better root systems and the number and activity of beneficial soil organisms. The effectiveness of SRI cultivation practices has been shown in over 50 countries, including the major rice producers in the world such as India, China, Vietnam, Cambodia and Philippines (Katambara *et al.* 2013) as well as in Indonesia.

Certain basic principles of SRI method can be identified, including, planting of young seedlings (8–12 days), planting of single seedlings (just one seedling per hill), wider spacing (usually 25 cm × 25 cm), maintaining moist soil condition (without flooding), and control of weeds by mechanical weeding, which improves soil aeration while eliminates the weeds. It is also recommended to use organic fertilizers (Barison & Uphoff 2011). However, SRI method can be applied using inorganic fertilizer or combination of organic and inorganic fertilizers that aims for increasing of nutrient amounts and type (Lin *et al.* 2011). SRI practices contrast with conventional method which generally involves considerably older seedlings (25 days old or more), planting of 3–5 seedlings per hill, closer spacing (20 cm × 20 cm, or less), maintaining soil condition mostly flooded, and fertilization mostly using inorganic fertilizers (Kediyal & Dimri 2009).

The advantages of application of SRI method compared to the conventional method are less seed requirement, water savings up to 50%, reduction in the use of inorganic fertilizers by 50% if coupled with 50% organic fertilizer, or some combination of organic fertilizer and biological fertilizer, reduction in production costs by 20%, and increase in yield (Hutabarat 2011).

Physiology of rice under conventional cultivation method has been widely reported, however, the physiology of rice plants under SRI cultivation method which supports high yield has received only

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limited study (e.g. Thakur *et al.* 2011; Mishra & Salokhe 2010), even SRI methods have been used in some number of countries. For example, SRI method applied in Afghanistan increased rice production by 66% compared to the conventional method (Thomas & Ramzi 2010). Similar results were reported in Iraq, where rice production increased by 42% with SRI method (Hameed *et al.* 2011). SRI method applied in eastern Indonesia (Nusa Tenggara) with a large number of comparison trials (>11,000) over nine seasons was able to increase rice production by 78% (Sato *et al.* 2011), whereas in Situ Gede, West Java, it was increase by 33% (Bakrie *et al.* 2010). As shown, the increase in rice yield of SRI method has a wide range. It is influenced primarily by soil microbes, which can vary widely under soil and climatic conditions in different places. Microbial closely related to soil health. The good aeration soil could maximize aerobic microbial activity (Araújo *et al.* 2009).

This research was conducted to assess the effects of cultivation methods on the rice plant's physiology. Thus, this research measured and evaluated differences in key physiological parameters, namely photosynthetic and transpiration rates of rice in response to SRI cultivation methods, comparing these with conventional rice cultivation methods, and to see their influence on growth and grain yield.

2. Materials and Methods

This research was conducted from October 2012 to September 2013 in Sindang Barang, Jero village, sub-district West Bogor, Bogor, West Java, Indonesia. The materials used were rice seed (Ciherang variety); chemical fertilizer including urea (45% N), SP-36 (39% P_2O_5), KCl (60% K_2O), and compost enriched with plant growth-promoting rhizobacteria (*Bacillus* sp., *Pseudomonas* sp., *Azospirillum* sp., and *Azotobacter* sp.) collected from the Laboratory of Microbiology in the Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University. Measurements of photosynthesis, transpiration and leaf temperature were taken using the LI-COR Biosciences device (Nebraska, USA) at photosynthetically active radiation (PAR) 600–1200 nm and measured at 09:00–11:30, and chlorophyll content was determined according to the Arnon method (1949), which was measured by spectrophotometer type Spectro Genesys™ 20 (Massachusetts, USA).

The study was conducted using a randomized complete block design in which the methods of rice cultivation evaluated were the conventional method and the SRI. The size of the experimental plots was 4 m × 5 m (20 m^2), and each treatment was replicated five times.

Seedlings were prepared by soaking the seeds in warm water for 24 hours, then air-drained and incubated for 2 days until germination. In the SRI method, the seedlings were planted in a tray, with soil and organic fertilizers enriched by biofertilizers (1:1 v/v), and were grown for 10 days. For the conventional method, seeds that had been incubated for 2 days and germinated were sown into a standard nursery for 25 days before transplanting using usual practices. The main differences between conventional and SRI rice cultivation methods are described in Table 1.

Table 1. Comparison between conventional and system of rice intensification rice cultivation method

Planting	Conventional	System of rice intensification
a. Age of transplanted seedlings	25 d after sowing	10 d after sowing (60% less)
b. Spacing	20 cm × 20 cm	25 cm × 25 cm (25% wider)
c. Number of seedlings per hill	3 Seedlings per hill	1 Seedling per hill (33% fewer)
d. Number of seedlings per m^2	75 Seedlings per m^2	16 Seedlings per m^2 (80% fewer)
e. Number of hills per m^2	25 Hills per m^2	16 Plants per m^2 (36% fewer)
f. Irrigation	Flooding continuously	Soil was kept moist

With respect to nutrient provision, both SRI and conventional treatments used the same type, dose, timing, and application of fertilizers, so soil nutrient amendments were not a variable in this trial. In here, we did not evaluate nutrient variations as a factor affecting production. In this experiment, the fertilizer application was 50% inorganic (125 kg urea/ha, 100 kg SP-36/ha, and 50 kg KCl/ha, which was equivalent to 250 g urea/plot, 200 g SP-36/plot, and 100 g KCl/plot) and 50% organic (2.5 t/ha, equivalent to 5 kg/plot). The organic fertilizers used in this research were compost enriched with biofertilizers, applied at transplanting together with SP-36 and KCl fertilizers, while urea was applied twice, half dosage was during transplanting and the remaining was 35 days after planting.

In the SRI method, to keep soil moist, a trench along the inner edge of the plot (size 20 cm × 20 cm × 30 cm) was flooded with water. Shortly before weeding, plots were flooded with a water level of about 2 cm. Weeding was carried out at 10, 20, and 30 days after planting using a conoweeder to ensure topsoil aeration. In the conventional method, flooded water was supplied continuously with water level of about 5 cm until 105 days after sowing (DAS). Weeding of the conventional method plots was performed at 10 and 20 days after planting manually by hand. For both cultivation methods, water was drained 5 days before harvest. Harvest of both SRI and conventional plots was carried out 110 DAS, when around 90%–95% of rice grains turned to yellow.

The vegetative growth parameters measured were plant height, leaf area, tiller number, leaf number, shoot dry weight at 70 and 110 DAS, width of the canopy at 20 cm above the soil's surface at 70 DAS, number of productive tillers per hill, and number of productive tillers per square-meter.

The generative growth parameters observed were panicle length, number of filled grains per hill, number of total grains per hill, percentage of empty grains, grain dry weight per hill, weight of 1000 grains, grain dry weight at harvest per square-meter, and grain dry weight per square-meter (yield after drying under the sun).

Physiological parameters observed were the photosynthesis rate (A), transpiration rate (E), and leaf temperature (Tleaf) using a LI-COR Biosciences device (Nebraska, USA) at PAR 600–1200 nm and measured at 09:00–11:30; chlorophyll content was determined according to the Arnon method (1949), using spectrophotometer type Spectro Genesys™ 20 (Massachusetts, USA), with observations made at four phases of growth (vegetative, flowering, grain filling, mature grain); nitrogen content at 70 DAS was determined according to the Kjeldahl method (Jones 1991), nitrogen uptake was obtained by multiplying the nitrogen content with the leaves' dry weight of rice plants per hill, and phosphorus content at 70 DAS was determined according to the wet-ashing method using HNO_3 and $HClO_4$ and measured by ultraviolet–visible spectrophotometer, phosphorus uptake was obtained by multiplying the phosphorus content with the leaves' dry weight of rice plants per hill. All the data were analyzed statistically using the independent t test at 5% probability.

3. Results

3.1. Effects of cultivation methods on vegetative growth

Implementation of SRI method resulted in significantly different measurements ($p < 0.05$) in plant height, leaf area, tiller number per hill, and leaf number compared to the conventional method at 32–70 DAS (Figures 1A–C). Plant height using SRI method at 32, 46,

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