

# Planting pattern affects root system development, resistance to water transport, and afternoon depression in photosynthesis in rice plants

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## Abstract

A planting pattern in which each hill contains one rice plant (planting pattern I) results in a higher yield of dry matter, especially during the reproductive stage, than a planting pattern in which each hill contains three plants (planting pattern III). Root system development, resistance to water transport, and afternoon depression in photosynthesis were compared between plants in planting patterns I and III. The number of crown roots and root length density per stem were significantly larger in plants in planting pattern I when compared to those in planting pattern III. In the ripening stage, the resistance to water transport and the afternoon depression in photosynthesis tended to be smaller in plants in planting pattern I. The larger capacity of water uptake and the smaller afternoon depression of photosynthesis may contribute to the larger yield of dry matter from plants in planting pattern I compared to plants in planting pattern III.

## Media summary

Planting a single rice plant per hill results in a smaller afternoon depression in photosynthesis because of a better-developed root system and a decreased resistance to water transport.

## Keywords

Direct-sown plants, Photosynthesis, Root length density, Submerged condition, Water stress, Water uptake capacity.

## Introduction

Rice planted in such a manner that each hill contains one plant (planting pattern I) produces a higher yield of dry matter than rice planted so that each hill contains three plants (planting pattern III). This effect was noted in both transplanted and direct-sown plants and was most pronounced during the reproductive stage (San-oh et al. 2004). The higher yield of dry matter is associated with the production of heavier grains in these plants (Table 1). Planting pattern I results in a canopy that consists of more erect leaves and the extinction coefficient of the canopy is smaller for these plants than for those in planting pattern III (San-oh et al. 2004). In addition, plants in planting pattern I produce a larger number of crown roots when compared to those in planting pattern III.

**Table 1 Dry matter accumulation ( $\text{kg m}^{-2}$ ) and grain yield ( $\text{g m}^{-2}$ ) in direct-sown plants of rice cultivars, Takanari, Kinuhikari and Dontokoi.**

Year		Takanari			Kinuhikari			Dontokoi		
		I	III	t-test	I	III	t-test	I	III	t-test
2002	Dry weight	2.17	1.87	*	1.70	1.50	*	—	—	

	Yield	936	831	*	625	588	*	—	—	
2003	Dry weight	2.15	1.74	*	—	—		1.85	1.63	*
	Yield	941	731	*	—	—		712	655	*

I and III represent the planting pattern I and III (see text), respectively. Dry weight of aboveground parts at harvest. Yield is given for water content of 14.5%. \*Means are significantly different at the 5% level (n=3) between planting patterns.

On clear days, leaf stomatal conductance and the rate of leaf photosynthesis decrease at midday because of water stress under intense transpiration. In rice plants this process occurs even when plants are grown under submerged conditions (Ishihara and Saito 1987). The degree of the midday and afternoon depression in photosynthesis is affected significantly by the root water uptake capacity (Hirasawa et al. 1992; Jiang et al. 1988). The capacity of water uptake is higher in the plants with better-developed root systems than in those with poor root systems (Hirasawa et al. 1992). Here, we compared the resistance to water transport and the afternoon depression in photosynthesis between planting patterns I and III for direct-sown rice plants in a submerged paddy field.

## Materials and Methods

### *Materials and cultivation of plants*

Rice plants (*Oryza sativa* L. cv. Takanari) were grown in the paddy field of the University Farm (30° 41' N latitude, 139° 29' E longitude) in alluvial soil (clay loam) from the Tama River. Plants were sown on April 30, 2003 and grown at a density of 51.3 (15 cm<sup>2</sup> × 13 cm) hills m<sup>-2</sup> with one plant per hill (planting pattern I) and at a density of 17.5 (30 cm<sup>2</sup> × 19 cm) hills m<sup>-2</sup> with three plants per hill (planting pattern III). As a basal dressing, manure was applied at a rate of about 2 kg m<sup>-2</sup> and chemical fertilizer was applied at the rate of 3.0 g each per m<sup>2</sup> for N and K<sub>2</sub>O at the panicle formation stage and at the full heading time. Heading (50% heading) occurred on August 16. The experiment was designed with three randomly arranged replicates.

### *Measurements of the number of crown roots and root length density*

To measure the number of crown roots, a soil core of 15 cm in diameter and about 20 cm in length from a hill with an average number of panicles was taken with a tinplate cylinder. To determine root length density, a soil core of 5 cm in diameter and 50 cm in length from a hill with an average number of panicles was taken with a cylinder tube (FV-493-1MB; Fujiwara Factory, Tokyo). The length of the collected roots were measured by the line intersect method (Tennant 1975).

### *Measurement of the resistance to water transport*

Because the plants were grown under submerged conditions, soil water potential could be regarded as 0 MPa. Consequently, according to a previous report (Hirasawa and Ishihara 1991), the resistance to water transport through roots to a leaf was calculated as follows:  $= -\Psi_x / T$  here  $\Psi_x$  is the leaf xylem water potential and T is the transpiration rate on the basis of leaf area. The resistance to water transport was compared under the conditions of intense transpiration (Hirasawa and Ishihara 1991). The transpiration rate was measured on a single, attached leaf with an acrylic assimilation chamber. Air with a dew point controlled at about 10 °C with an accuracy of ±0.1 °C was pumped into the chamber at the rate of 50 cm<sup>3</sup> s<sup>-1</sup>. Humidity of the air pumped into and away from the chamber was measured with a dew point meter (Model 660; EG & G Inc., Waltham, MA). After the transpiration rate became constant, the leaf xylem water potential was measured with a pressure chamber (Model 3005; Soil Moisture Equipment Inc.,

Santa Barbara, CA). The leaf was covered with a moist polyethylene bag immediately before excising. The cylindrical inner wall of the pressure chamber was covered with wet filter paper to prevent transpirationary water loss. The chamber was pressurized with compressed air at a rate of about 0.003 MPa s<sup>-1</sup>.

#### *Measurement of photosynthetic rate*

The rate of leaf photosynthesis was measured on the same central portion of a leaf at different times with a gas-exchange apparatus (LI-6200; LI-COR, Lincoln, NE). During the measurement, the leaf surface was held perpendicular to the sun's rays. The measurement was repeated three times in 30 seconds. The three readings did not differ in any consistent or substantial manner and the mean was taken as the measured value. Measurement started at air CO<sub>2</sub> concentration of about 370 µmol mol<sup>-1</sup> in the assimilation chamber.

## **Results**

#### *Number of crown roots and root length density*

The number of crown roots per stem was significantly larger in plants in planting pattern I than those in planting pattern III (Table 2). This confirmed the result of the previous study (San-oh et al. 2004). Root length density per stem was also significantly larger in plants in planting pattern I (Table 2).

**Table 2 The numbers of crown roots and root length density at soil layers of 25 to 37.5 cm (A) and 37.5 to 50 cm (B) from the soil surface.**

Planting pattern	No. of crown roots  per stem	Root length density per stem  (cm cm <sup>-3</sup> )	
		A	B
I	82.2 ? 3.1	6.18 ? 2.35	0.23 ? 0.05
III	58.3 ? 2.2	1.74 ? 0.07	0.10 ? 0.05
t-test	**	*	*

\*, \*\*: Means are different at the level of 5 % and 1 %, respectively.

#### *Resistance to water transport from roots to a leaf*

The resistance to water transport from roots to the flag leaf and to the third leaf increased with time from the early ripening stage to the late ripening stage (Table 3). This increase was larger for the third leaf than for the flag leaf. Although there were no differences in the resistance to any leaves at the early ripening stage between the plants, the resistance to the flag and the third leaves at the middle ripening stage and the resistance to the flag leaf at the late ripening stage tended to be smaller in plants in planting pattern I than those in planting pattern III.

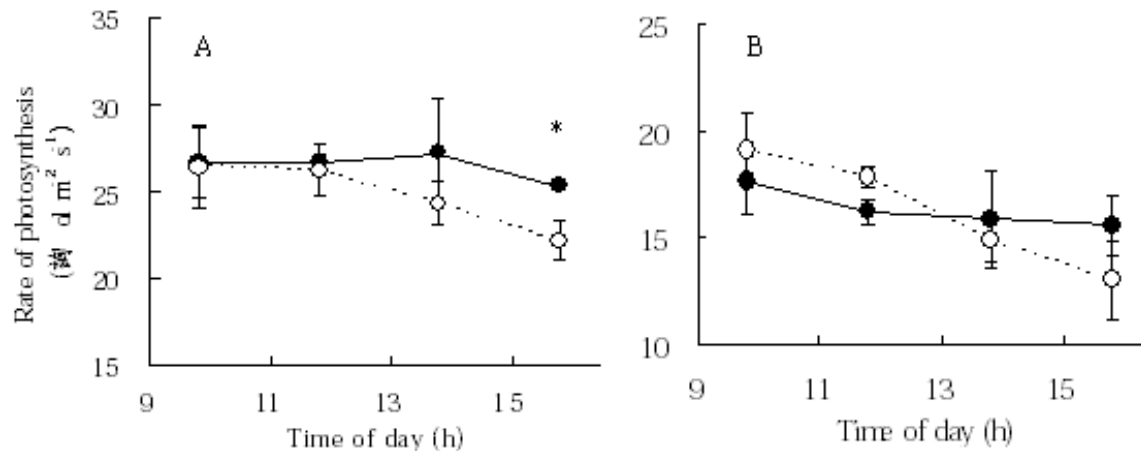
**Table 3 The resistance to water transport from roots to a leaf.**

Growth stage	Leaf position on a stem	Planting pattern	Transpiration rate (mmol m <sup>-2</sup> s <sup>-1</sup> )	Resistance to water transport (?10 <sup>6</sup> MPa s m <sup>-1</sup> )
Early ripening	Flag	I	4.3~9.0	3.75 ? 0.70
		III	3.2~9.4	3.76 ? 0.39
	3rd	I	3.4~7.4	4.34 ? 0.23
		III	3.9~6.1	4.47 ? 0.15
Middle ripening	Flag	I	2.5~9.7	3.87 ? 0.34
		III	2.4~9.3	4.56 ? 0.37
	3rd	I	3.1~5.8	5.13 ? 0.25
		III	3.5~6.2	6.23 ? 0.47
Late ripening	Flag	I	1.7~5.3	6.10 ? 0.41
		III	1.6~4.9	7.16 ? 0.75

I and III represent planting pattern I and III, respectively. Mean ? standard deviation (n=3).

#### *The afternoon depression in photosynthesis*

The rate of photosynthesis decreased in the afternoon of a clear day for the flag and third leaves (Fig. 1). At the early ripening stage, the reduction in the rate of photosynthesis was smaller in plants in planting pattern I than those in planting pattern III. We compared the afternoon depression in photosynthesis as the ratio of the minimum rate of photosynthesis in the afternoon and the maximum rate in the morning. The afternoon depression tended to be smaller in the flag leaf in plants in planting pattern I than those in planting pattern III at the early and late ripening stages (data not shown).



**Fig. 1** Diurnal changes in the rate of photosynthesis of the flag leaf (A) and the third leaf (B) on a clear day at the early ripening stage. Closed and open circles represent the plants in planting pattern I and III, respectively. The rate of photosynthesis was measured under the light intensity higher than 1,200 μmol m<sup>-2</sup> s<sup>-1</sup> of PAR. Maximum air temperature and minimum relative humidity were 36°C and 54%, respectively. \*Means are significantly different at the 5% level.

## Conclusion

Rice plants in planting pattern I had a better-developed root system than plants in planting pattern III. A better development of the root system was associated with a decreased resistance to water transport and a smaller afternoon depression in photosynthesis. The larger water uptake capacity and the reduced afternoon depression of photosynthesis may contribute to the higher yield of dry matter from plants in planting pattern I compared to plants in planting pattern III.

## References

- Hirasawa T and Ishihara K (1991). On resistance to water transport in crop plants for estimating water uptake ability under intense transpiration. *Japanese Journal of Crop Science* 60, 174-183.
- Hirasawa T, Tsuchida M and Ishihara K (1992). Relationship between resistance to water transport and exudation rate and the effect of the resistance on the midday depression of stomatal aperture in rice plants. *Japanese Journal of Crop Science* 61, 145-152.
- Ishihara K and Saito S (1987). Diurnal courses of photosynthesis, transpiration, and diffusive conductance in the single-leaf of the rice plants grown in the paddy field under submerged condition. *Japanese Journal of Crop Science* 56, 8-17.
- Jiang C-Z, Hirasawa T and Ishihara K (1988). Physiological and ecological characteristics of high yielding varieties in rice plants. II. Leaf photosynthetic rates. *Japanese Journal of Crop Science* 57, 139-145.
- San-oh Y, Mano Y, Ookawa T and Hirasawa T (2004). Comparison of dry matter production and associated characteristics between direct-sown and transplanted rice plants in a submerged paddy field and relationships to planting patterns. *Field Crops Research* (in press).
- Tennant D (1975). A test of a modified line intersect method of estimating root length. *Journal of Ecology* 63, 995-1001.