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Development of Automatic Fog Culture System for Year-Round Rice Production in Greenhouse

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Abstract

Though there are some drawbacks in the design of this rice culture system, the results showed that these can be alleviated. The culture system was set up in a glass greenhouse to avoid yield loss due to typhoon and heavy rain which led to an inadequate amount of solar radiation even during the summer. Inclining the seeding bed southwards at 30° did not enable to improve the light absorption. Some favorable aspects of this fog culture system, however, are worth considering. Subsoil water temperature particularly in winter became more manageable. Carbon dioxide concentration in a particular growth phase could be enhanced. Nutrients could be replenished in the most suitable growing period and with the most appropriate amount. The oxygen supply to the root system was provided adequately during atomization. With all these advantages, year-round production increased 3 times or more due to the absence of seasonal effect. This experiment also indicated that the apparent photosynthetic rate could be enhanced by increasing the amount of insolation and solar energy conversion. This should certainly exert a beneficial effect on the panicle number, ripening efficiency and grain-straw ratio or total grain yield in general. Lastly, our group aims at redesigning the set-up in order to increase the production. In Japan, we are focusing on a stable, high-yielding and automatic year-round rice production while aiming at the same time at preserving the environment by reducing the consumption of expendable energy, To some extent, this study provides a basis for the development of a technology for desert or arid areas and subfrigid zones to increase productivity.

Discipline: Crop production/Agricultural facilities
Additional key words: apparent photosynthetic rate, grain-straw ratio, root system, solar radiation

Introduction

More than half of the 5.8 billion world population is eating rice as staple food. Though rice is usually produced in the tropical zone, Japan has been cultivating rice which is genetically resistant to cold temperature. Moreover, through recent varietal improvement studies, high-yielding cultivars with good quality have been developed. Nowadays, among the rice-producing countries, Japan is considered to be the world's northernmost area.

With the progress in farming technology and varietal improvement, Japanese rice can now withstand cold weather injury[2,4]. The cold summer in 1993 caused the greatest postwar rice shortage in Japan which led to emergency rice importation. Another factor which is a cause for concern regarding the future supply of rice, the staple food in Japan, is the ageing population of rice farmers with no successors to continue rice farming. Recently, for rice culture as well as for the production of other crops, heavy input of chemicals and other practices causing environmental pollution have become a global problem[5,6].

The objective of this study was to develop a rice culture system that would: 1) minimize yield losses due to natural disasters, 2) reduce environmental pollution, and 3) lead to sustainable year-round production.

This paper reports partial results obtained during several years of research on the development of an automatic fog culture system for rice production.

Automatic fog culture system set-up

A system similar to that shown in Fig. 1 was set up in a glass greenhouse. The cultivation area

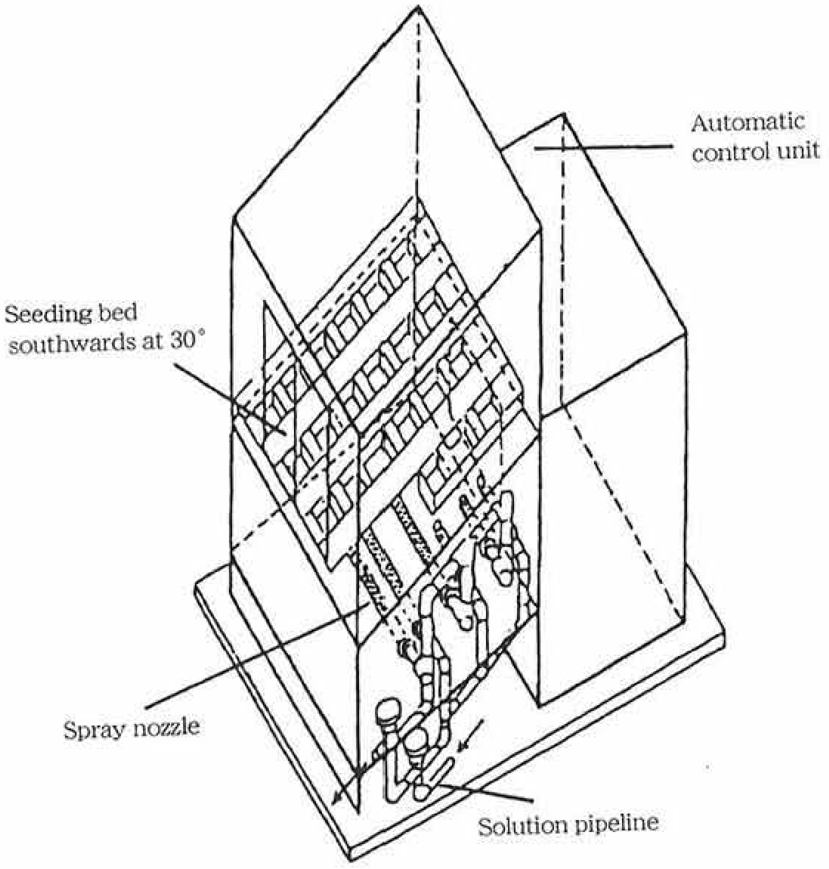

Fig. 1. Automatic fog culture system

was 172 cm long and 235 cm wide. To obtain satisfactory sunlight penetration within the rice population and during the winter season, seeding beds were inclined southwards at 30°. A vinyl chloride culture room was constructed inside the glass greenhouse. Room temperature was controlled by an air-conditioner to maintain the most suitable temperature for paddy production. A small-scale fan was set up over the paddy so that the leaves would sway constantly to a certain degree. This ventilation helped to secure a satisfactory CO_2 diffusion and a high canopy photosynthetic rate. It was reported that under lowland field conditions, root respiratory activity decreases as the paddy develops and reaches the reproductive phase, causing a remarkable decrease in yield, mainly due to an inadequate oxygen supply in the rhizosphere[3]. The special characteristic of our rice fog culture set-up is that the root system is aerated. The nutrient solution is atomized intermittently such that the O_2 supply is satisfactory and root growth is optimum. Plant growth decline due to root rot can be avoided using this culture system.

The composition of the basic nutrient solution (Kasugai A) is shown in Table 1. The concentration of the solution was renewed weekly to compensate the plant nutrient uptake. The nutrient solution temperature, pH and EC were monitored regularly. The pH was adjusted automatically with a NaOH solution using a peristaltic pump to pH 5.0–5.5 which is the optimum pH for rice. The temperature was maintained at 25°C. After noting the difference between the daytime and nighttime temperature, the

Table 1. Kasugai A solution used in this experiment

(Unit: mg/L)

$(NH_4)_2SO_4$	188.7
Na_2HPO_4	40.0
$CaCl_2$	7.9
Fe–EDTA	27.4
$MnCl_2$	0.75
KCl	47.5
SiO_2	137.3
N	40
P_2O_5	20
CaO	4
MgO	6
K_2O	30

atomization time was set to be longer during the daytime. During winter the root space and seedbed temperature were kept at 25°C but in the summer planting season the temperature was not regulated.

Foam styrol beads 5.8 mm in diameter were glued onto the bedding material (STIRODOREN, Mitsubishi Chemical BASF Co. Ltd.). With this seeding block, sufficient space is provided between beads so that root elongation becomes easier. Seeding holes were bored as shown in Fig. 2. The orientation of the seed to the seeding box and the space for tillers are illustrated in Fig. 3. The sown seeds were covered with sand up to a thickness of 1 cm to prevent the emerging seeds from moving upwards due to the pressure from the elongating roots. In fact, the permeability of STIRODOREN was quite adequate for the rooting of the rice plant (Fig. 4). Since rice shows intrinsically a high tillering potential, the sowing holes were oriented transversally to prevent lodging. After heading, when the translocation of photosynthates to the paddy starts, the ear weight becomes heavier and the culm's bending momentum also increases. In the present planting system, however, lodging was not observed because the culm was confined within the walls of the rectangular seeding hole. Moreover, with this bedding material, hill to hill distance and interrow spacing could be manipulated in response to the growth stage such that an optimum leaf area index could be obtained.

In the tropics, the major activity in rice culture is the transplanting of seedlings in the field. In the current system, seeds are sown directly and cultural management is possible from sowing to harvest. Since the seedlings do not undergo transplanting injury, the growing period is shorter[9]. The main advantage of hydroponics is that fertilizer management is considerably easier and can be adjusted depending on the growth stage such that the plant intrinsic photosynthetic capacity can be enhanced.

Furthermore, by using fluorescent lamps and a timer, photoperiodism can be regulated and the plant growth phase modified. The potential of an automatic year-round production scheme is the most remarkable advantage of the current planting system over field cultivation. Fig. 5 illustrates the seeding bed after sowing (vinyl chloride sheets removed).

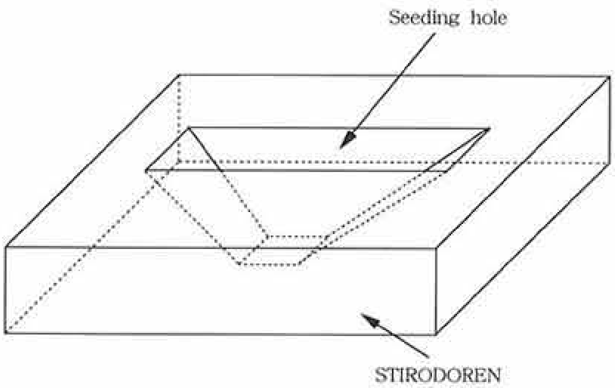

Fig. 2. Seeding block and seeding hole

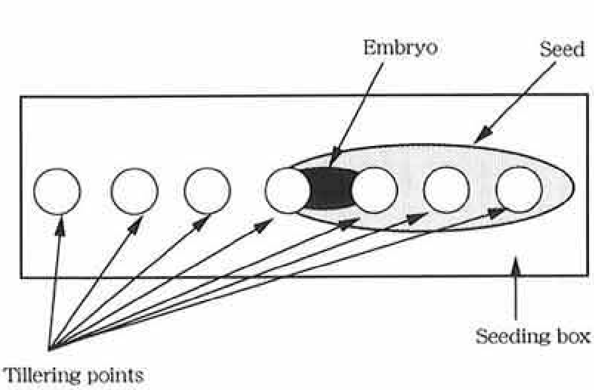

Fig. 3. Outline of seeding method

Fig. 4. Seeding block, STIRODOREN and rooting of rice

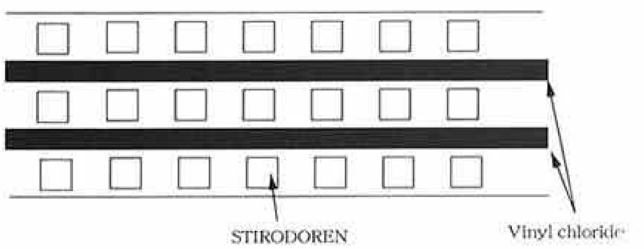

Fig. 5. Seeding bed

The nutrient solution is sprayed on both top and root sections. This spraying also supplies the water required by the emerging seeds or seedlings. As the seedlings grow, only the underground area is atomized. The time of spraying depends on the elongation of the roots such that nutrient absorption is sufficient for plant growth.

Materials and methods

Early season variety (*Oryza sativa* L. cv. Koshihikari) and standard season variety (*O. sativa* L. cv. Harebare) were used in this fog culture experiment. After seed treatment to hasten germination, both varieties were sown at a row spacing of 17 cm and hill distance of 12 cm and 14 cm on March 7, 1992. Ordinary tap water was used for the first 6 days before replenishing with the basic nutrient solution (Kasugai A) at gradually increasing concentrations of 0.25, 12.5, 25, 50 to 100%. Fig. 6 clearly shows the relative concentration of the Kasugai A solution in relation to the plant age.

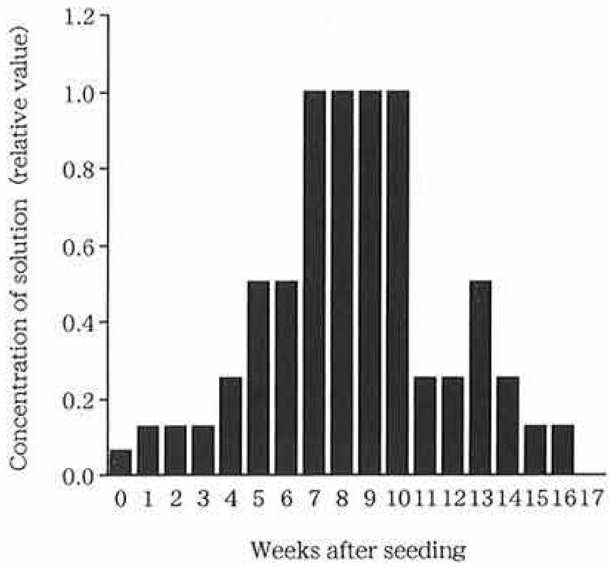

Fig. 6. Relative concentrations of Kasugai A solution used in fog culture system

Between March 12 – June 1, illumination was provided by fluorescent lamps for 4 h from 6 pm – 10 pm to simulate a long-day environment. Heading was observed on July 10 for Koshihikari, while Harebare headed 8 days later. Apparent photosynthetic rate was measured before heading (July 2). Leaf age, plant length, tiller number, internode length, root length, grain yield and yield components were determined at the harvest stage on August 24, 1992.

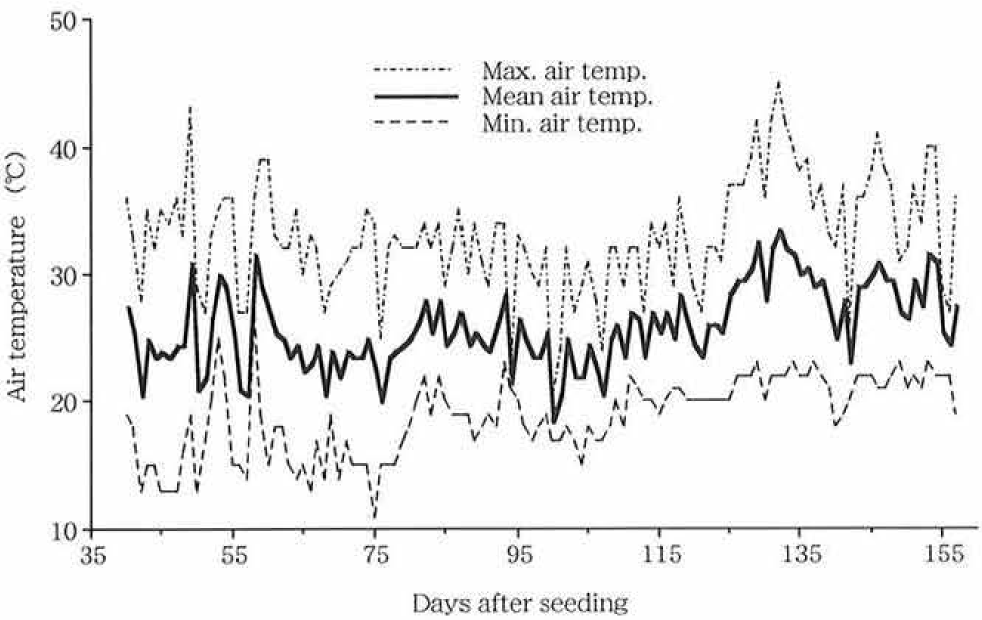

Fig. 7. Changes in air temperature during the experiment

Results and discussion

The fluctuations in the maximum, minimum and mean temperatures during the growing period are shown in Fig. 7. The daily maximum temperature exceeded 40°C several times. Moreover, in the second half of the growing period, particularly during the ripening stage, a relatively high temperature was observed. The high temperature after the rainy season affected ripening. Even the daily mean temperature tended to affect the plant growth during the later stage. Tange (1973)[7] reported that for rice growth the optimum temperature is in the range of 30–32°C. Since the present rice culture system was set up inside a glass greenhouse, the temperature build-up was higher than the ambient temperature in the field. The comparatively high temperature was also compounded by the low cooling-off efficiency of the set-up. These observations suggest that the fog culture system could be improved by avoiding the set-up inside a glass or greenhouse with a low cooling efficiency.

The concentration of the nutrient solution was adjusted based on the leaf color and growth conditions. Regarding the nutrient balance, a nearly normal transition was observed from the maximum tillering stage to the grain maturation stage. The growing tillers during the active tillering stage are shown in Fig. 8. The changes in the leaf age for both varieties are depicted in Fig. 9. The turning point of the leaf-emergence rate corresponded to the 8th leaf stage. After the 8th leaf had emerged, the leaf-emergence rate was one leaf higher in the Harebare variety. This pattern continued until harvest. Nevertheless, based on the leaf age the growth was considered to be normal. In Fig. 10 the changes in plant length are compared. Harebare grew up to 100 cm while Koshihikari reached 120 cm.

Fig. 8. Active tillering stage of rice

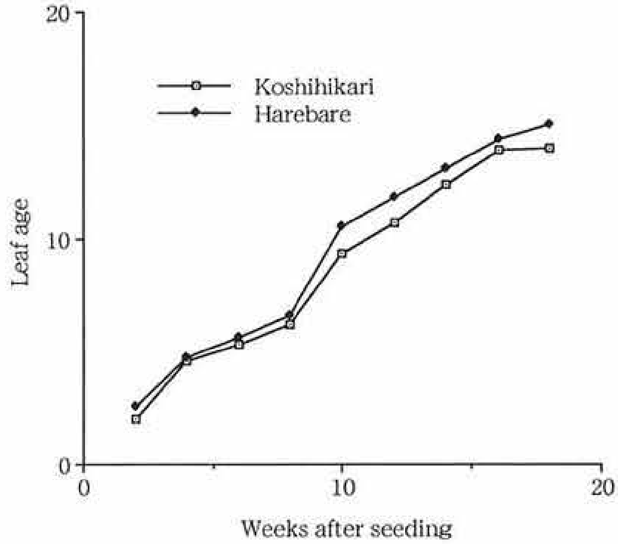

Fig. 9. Changes in leaf age during the experiment

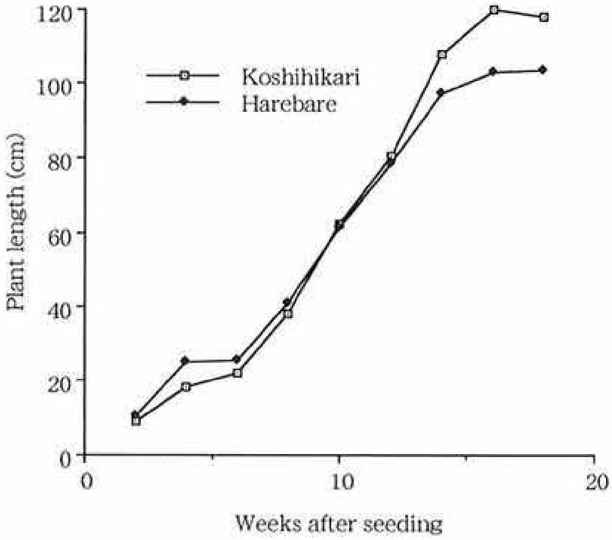

Fig. 10. Changes in plant length

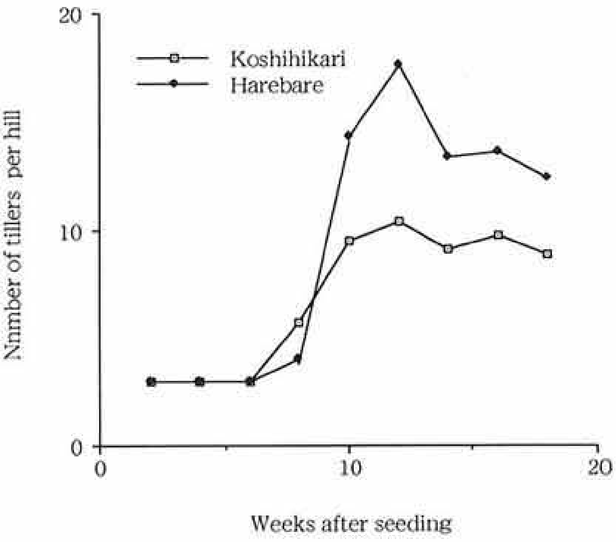

Fig. 11. Changes in the number of tillers

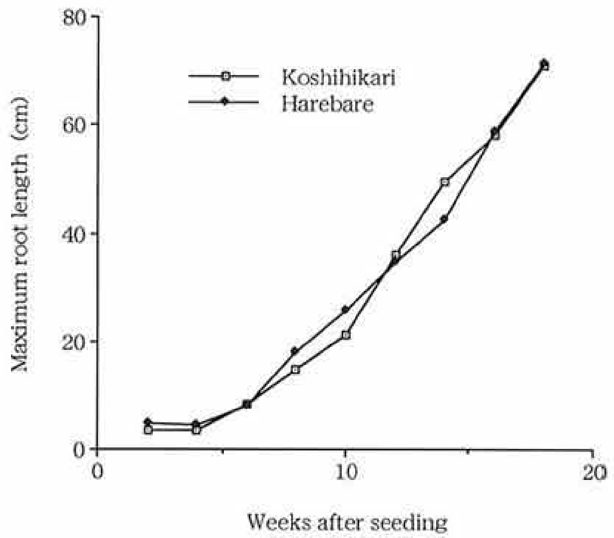

Fig. 12. Changes in maximum root length

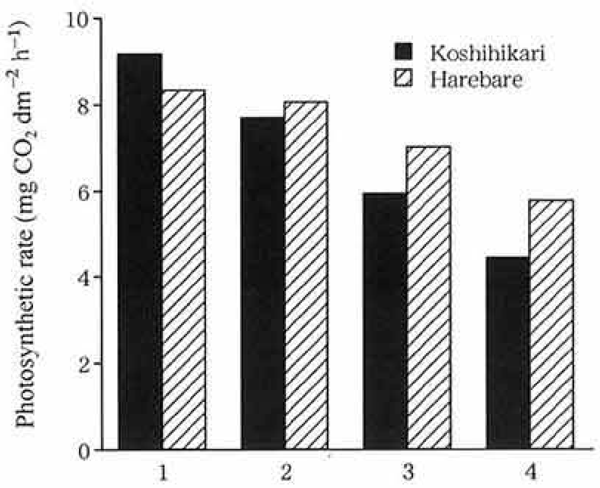

Fig. 13. Comparison of photosynthetic rate among leaf positions from top

Elongated growth was observed in the Koshihikari variety which did not affect significantly the final yield. Fig. 11 shows the changes in the tillering pattern. The Harebare variety continued to develop more tillers during the most active tillering stage. Tiller number was high, as much as 12 tillers per hill which also resulted in a large number of non-productive tillers. On the other hand, non-productive tillers were not observed in the Koshihikari variety. This difference clearly indicates that the tillering potential is a varietal characteristic. In this experiment, the planting density was higher than under the usual paddy field conditions. Based on the response of Koshihikari to dense planting, this variety could be considered to belong to the erect plant type. The changes in the maximum root length are shown in Fig. 12. Both varieties responded similarly and no remarkable differences were observed.

In Fig. 13, the apparent photosynthetic rate of the top 4 leaves was compared at light saturation. The top, most actively developing leaf was designated as Leaf 1 and Leaf 2 was the leaf just below Leaf 1, etc. Data were gathered on a clear, fine day just before heading. The apparent photosynthetic rate in each leaf was highest in Leaf 1 but the rate decreased with the decrease of the leaf position. In Koshihikari the rate of decline was more remarkable. Leaves 2–4 in Harebare tended to display a higher rate than leaves in the same position in Koshihikari. The level of the photosynthetic rate in either variety, however, was only 1/3 of the rate in the rice plants grown under normal field conditions. During the measurement, leaf sampling units were maintained in the vertical position and the leaf surface received sunlight directly. At a normal light intensity, data were not considerably low. The low photosynthetic rate was mainly due to the reduced penetration of sunlight because the system was set up inside a glass greenhouse. The glass wall acted as a twofold screen and decreased the sunlight intensity by as much as threefold. Though some plants show a low light compensation point, lettuce, honewort and other vegetables for instance can yield optimally even at 20,000 lux[1] while rice requires at least 50,000 lux[8].

The top and root system at harvest are shown in Figs. 14 and 15, respectively. After harvesting, internode length and yield components were determined. To reduce the experimental error, data obtained from hills with good growth and poor growth were segregated. Fig. 16 shows the length of the internode from the top. In both varieties, the

Fig. 14. Panicles at harvest stage

Fig. 15. Root system at harvest stage

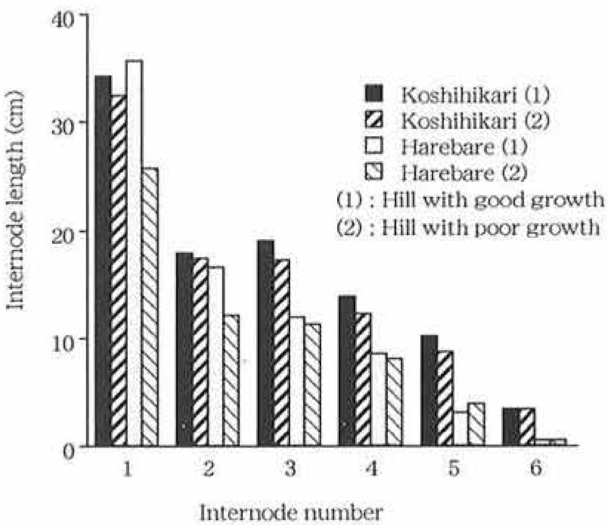

Fig. 16. Comparison of length of internode from top

topmost internode was the longest while there was an abrupt decline in the second internode. The relative decrease between internodes 2, 3, 4, and 5 was gradual. In Koshihikari, regardless of the internode position, the growth stand did not affect the internode length. In Harebare, however, the length of internodes 1 and 2 from hills with poor growth was considerably shorter, presumably due to mutual shading which led to a large number of non-productive tillers in the Harebare variety. The decline in the over-all apparent photosynthesis was due to the low light transmittance caused by dense tillering and short internodes.

The grain yield and yield components are listed in Table 2. Sampling was performed in 5 hills with 4 replications. In both varieties, the number of panicles per hill and 1,000 grain weight from rice hills with good growth were generally satisfactory. However, the number of panicles per hill and the percentage of ripened grains were very low. These 2 parameters contributed to the low grain yield. The

Table 2. Comparison of yield components among hills

	Number of panicles per hill	Number of spikelets per panicle	Percentage of ripened grains	1,000 grain weight (g)	Grain-straw ratio	Yield (kg/10 a)
Koshihikari (1)[a)]	21.6	60.2	69.7	21.2	0.37	808
Koshihikari (2)[b)]	6.8	58.0	48.6	18.9	0.19	108
Harebare (1)[a)]	25.0	62.7	32.9	19.8	0.15	463
Harebare (2)[b)]	6.4	28.3	17.2	18.2	0.047	23

a): (1); Hill with good growth, b): (2); Hill with poor growth.

maximum yield of Koshihikari was 808 kg/10 a and Harebare produced only half of this. The major difference may be attributed to the inefficient ripening in Harebare. Grain yield from hills with poor growth was even much lower mainly due to the small number of panicles and was aggravated by the large number of unfilled grains. One obvious reason for the low maximum yield was the light competition caused by dense planting. The plant density in the paddy field using a transplanting machine is usually 23 hills/m^2. In this experiment, at a hill distance of 12 cm the rice population was 49 hills/m^2. A distance of 17 cm then results in a population of 42 hills/m^2 or almost twice the normal paddy field population. The wide variation in the actual grain weight implies that some hills were dominant and were more efficient in tapping solar energy. Hills with few panicles were undoubtedly poor hills. In this experiment, if the hill distance had exceeded 17 cm (sparse planting density), it is probable that the yield would have been higher because the light competition effect would have been minimal.

Furthermore, comparison of the grain yield with the straw yield showed that the ratio was very low, suggesting that the plants did not receive enough insolation to sustain the ripening process. In general, low yield was expected because of the low light energy absorption. Our set-up, however, indicated that even when the solar radiation was low, rice production in a fog culture system was possible because the nutrients could be supplied when the plant required them most.

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