Response of Crop Photosynthesis of Rice to Climatic Conditions as Affected by the Canopy Architecture

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Since rice is grown in most diverse conditions of environment[7], environmental factors that limit its productivity vary from one area to the other. Among them radiant energy is universally important, determining productivity through various physical and physiological processes that are essential for rice plants to grow. Here we limit our scope to the role of visible radiant energy in the productivity of rice crop through crop photosynthesis.

The rate of crop photosynthesis depends on the leaf area index (LAI) and architecture of the canopy and on photosynthetic rate per unit leaf area. There are differences in photosynthetic rate of leaf between rice cultivars[11,12]; but these differences are little reflected in the differences in both crop dry weight[13] and grain yield[11]. On the other hand, canopy architecture has a strong influence on varietal differences in dry matter production[6]. The canopy architecture appears to be particularly important with rice, presumably because photosynthesis of rice leaves reaches light saturation at a relatively low light level compared with C4 cereals, such as maize and sorghum[5]. Conflicting results with maize as to the effect of canopy architecture on photosynthesis and yield[4] may be partly resulted from the characteristic of light response of maize.

The objective of our studies outlined here is to evaluate the varietal differences in canopy architecture in terms of crop photosynthesis at locations of different radiant regime.

Current status of the problem

General picture as to the response of crop photosynthesis to radiation as affected by stand geometry has been well established. In general, canopies with more erect leaves have a higher photosynthetic rate than those with horizontal leaves at high LAI, because of reduced light saturation of the upper leaves and more uniform distribution of light throughout the canopy[4]. T. Tanaka[15], for example, clearly demonstrated with rice that reducing the inclination (against the horizontal line) of leaves with weights reduced crop photosynthetic rate as well as dry matter production. Productive modern cultivars of rice tend to have more vertically inclined leaves than do older cultivars[14]. Therefore, IR-8, a variety of short stature with erect leaves, is generally regarded as the one of efficient canopy architecture with respect to light interception.

But, the influence of canopy architecture on crop photosynthesis can be modified by the level of incident radiation and the elevation of the sun. For instance, in conditions of temperate climate in Japan, the response of IR-8 to radiant environment during the period of grain-filling was far more sensitive than that of Lewang Tawng, a local cultivar of high stature with drooping leaves in Thailand (Keo Intabonsa, 1978, Ph.D. thesis, Kyoto University). Under the conditions of normal cultural practices, the percentage of ripened grains in IR-8 was much less than that in Lewang Tawng, but thinning at heading improved substantially the ripening of grains and thus the yield per plant in IR-8. Thus, light interception of erect-leaved canopy may not always be efficient, and it is important to evaluate the canopy architecture in relation to the specific radiant regimes for given locations.

So far, most studies on the comparisons of productivity of rice varieties for various locations are based on statistical analysis with yield data and climatic records of various degree of precision. Such studies, though practical and effective for certain occasions, appear not suitable for our present purpose, i.e., to evaluate canopy architecture in terms of light interception efficiency under various radiation environments. Dependable yield data for a variety with particular canopy architecture is only available for limited locations. Even with data collected from carefully conducted experiments, a number of other factors and processes that affect yield would obscure and disturb the influence of canopy architecture on crop photosynthesis. Moreover, such analysis can hardly reveal any physical and physiological mechanisms that are underlying in the response of our interest, and thus is of little use in identifying specific parameters that are responsible for differential crop behavior.

The approach we have chosen is the simulation with crop photosynthesis model based on Duncan et al.[3] The model is proved, with rice, to calculate the penetration of light and its effect on CO_2 flux with sufficient accuracy[9]. With this model, Duncan[2] has estimated the effect of leaf angle on crop photosynthesis of maize with hypothetical distribution of leaf inclination. McCree and Keener[10] elegantly demonstrated the model to be powerful in evaluating the architecture of actual canopies of three sorghum strains. For rice, however, no attempt has been made to evaluate the canopy architecture for various locations with this model or other similar ones.

Appoarch

The model we used is a version of the Duncan-Stewart model, as described by Van Bavel[16]. The model calculates the radiant energy distribution in the canopy, layer by layer, using, as inputs, the canopy architecture (leaf areas and angles in each layer of the canopy), the optical properties of the leaves, and the global irradiance. The global irradiance (incident solar radiation) data should be associated with the solar elevation. The radiant energy distribution is then used to obtain the photosynthetic rate of each layer by the light response of leaf photosynthesis. We used rectangular hyperbola for this response, excluding dark respiration by the leaves. We further assumed that the light response curve was the same for all the leaves in the canopy and that it was independent of other environmental variables and the pysiological state of the crop. Thus, we calculated the effect of canopy architecture on the response of the gross rate of photosynthesis to light, assuming all other factors are equal.

We simulated the effect of canopy architecture on crop photosynthesis around the period of ear emergenc with three canopy types for several locations of the world. Three crops were (i) "erect-leaved", (ii) "horizontally-leaved", and (iii) "ideally-leaved" ones. The leaf angle distributions for the first two were taken from the measurements made on IR-8 (i) and Manryo, a Japanese variety (ii) by Ito et al.[8] The 'ideally-leaved" crop is the one used by Duncan[2]: the leaves of the upper six layers are all vertical and the leaves of the bottom layer are horizontally extended. For all the three crops, we used the same light response and leaf optics obtained by Keener and McCree[9]. Thus, the three crops were assumed to be different in leaf angle distribution only. We selected eight locations[17] which represent major rice producing areas of the world and differ in radiant regime (global radiant level and solar elevation). With the above conditions, simulations were made for two cases; (a) the crops with LAI of 2.0 and (b) the crops with LAI of 8.0.

More details can be found in Kumashiro (1981, M.S. thesis, Kyoto University).

Table 1. Calculated rates of crop photosynthesis of three canopy types at eight locations of the world along with the average daily total of global irradiance for the month of heading to grain-filling period of rice

Location	Global irradiance (cal cm^{-2} day^{-1})	LAI=4			LAI=8		
		Id.	IR.	M.*	Id.	IR.	M.
Griffith, Australia	700	54.6**	51.4	49.8	87.6	77.8	67.3
Davis, USA	611	50.7	47.9	45.9	89.2	71.1	61.8
Madras, India	608	49.1	46.3	45.2	79.2	70.5	61.5
Los Baños, Philippiness	568	46.2	44.7	44.2	76.0	68.4	59.9
Bangkok, Thailand	516	43.5	42.1	41.9	71.2	64.3	56.4
Djakarta, Indonesia	451	40.8	38.5	38.4	65.1	58.2	51.7
Saga, Japan	444	41.3	38.9	38.3	64.3	57.6	50.9
Milano, Italy	430	40.6	38.6	36.7	61.1	55.5	48.6

* Id. for "ideally-leaved", IR. for IR-8 ("erect-leaved"), and M. for Manryo ("horizontally-leaved") crops.

** gCO_2 m^{-2} day^{-1}.

Crop photosynthesis of three canopy types at several locations of the world

Calculated rates of crop photosynthesis at eight locations are listed in Table 1 along with the average daily total of global irradiance for the month of heading to grain-filling period. Crop photosynthesis was higher at locations of higher incident solar radiation, regardless of canopy architecture and LAI. For instance, photosynthesis of IR-8 at Griffith, New South Wales, Australia is 1.4 times as high as at Saga, Saga Prefecture, Japan. Thus, high yield in the area of New South Wales, Australia[1] is at least partly attributable to high radiant level and resulting high photosynthetic rate of this area.

Though daily photosynthetic rates were consistently highest in the "ideal" crop and IR-8 ranked the second, the effect of canopy architecture was more evident at high LAI (LAI=8). At Griffith, for example, the relative advantage of IR-8 over Manryo was only 3% at LAI of 4, while it was 13% at LAI of 8. On the other hand, difference in the relative advantage of "erect-leaved" canopy over "horizontally-leaved" one between the areas of high and low radiant levels was strikingly small, although this may be resulted from coupled effect of solar elevation associated with varying locations.

Concluding remarks

Our results failed to indicate any location-specific superiority of "erect-leaved" crop over "horizontally-leaved" one. The relative advantage of IR-8 over Manryo at Griffith, the area of the highest radiant level we examined, was 13%, which differed little from 12% at Milano, the area of the lowest radiation. Thus, the "erect-leaved" crop is always efficient, as far as the response of crop photosynthesis to light is concerned.

Our results demonstrated the importance of canopy architecture in determining the rate of crop photosynthesis at high LAI. The maximum effect of leaf angle we obtained was 13%, while it was 10% for sorghum[10]. Thus, the importance of canopy architecture appears to be greater for rice than sorghum, though the different conditions preclude accurate comparisons.

Our results indicated that the rate of photosynthesis was higher in the area of higher incident radiation where the yield is also generally high. It is therefore probable that the increase in crop photosynthesis either due to the improved canopy architecture or higher solar radiation is reflected in grain yield in rice. If so, we could increase the potential yield of rice by another 10% by breeding rice plants which have the "ideal" canopy architecture.

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