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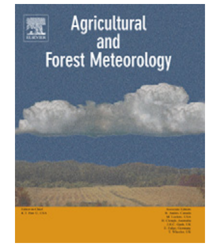

Diurnal and seasonal variation in bulk stomatal conductance of the rice canopy and its dependence on developmental stage

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ABSTRACT

Bulk stomatal conductance (g_S) is an important factor that expresses the effect of stomatal movements on water transfer between the plant and atmosphere at the canopy scale and is widely used as a parameter in many micrometeorological models. Diurnal and seasonal variations in g_S of the rice canopy were determined using a heat transfer model based on heat flux measurements in irrigated rice fields. Season-long observations from transplanting to maturation of rice plants were conducted to obtain heat flux data in a humid temperate climate at three experimental sites with widely differing cropping seasons in Japan. A double source model was used as the heat transfer model to calculate g_S. Seasonal variations in heat fluxes differed for sensible heat and latent heat. Sensible heat flux was smaller and relatively constant within the range −50 to 50 W m^{-2}, whereas latent heat flux showed large variations from 0 to 250 W m^{-2} throughout the growth period. It was suggested that this would be a common pattern for paddy rice fields in all cropping seasons. Diurnal variation in g_s showed a common trend in all growth periods with lower values in the morning and evening, and higher values during the midday because of its dependence on solar radiation. The relationship between absorbed solar radiation (S_{abs}) and g_s was determined using a Jarvis-type model for each growth period. Maximum values of bulk stomatal conductance (g_{Smax}) for saturated S_{abs} rapidly decreased from 0.06 to 0.02 m s^{-1} between the active tillering and panicle formation stages, and moderately decreased from 0.02 to 0.01 m s^{-1} during the ripening stage. This was considered to be due to the change in leaf chlorophyll concentration. Seasonal variation in g_{Smax} can be commonly expressed for all cropping seasons using the function of developmental stage (P_S). Using this function, the g_S value can be obtained easily at a given developmental stage, which makes it possible to use micrometeorological models in relation to rice phenological development for evaluating important factors, such as water temperature and transpiration, that affect rice production.

1. Introduction

Stomata play an important role in water, carbon and nutrient cycles by controlling water transfer in the soil-plant-atmosphere-continuum (SAPC). Stomatal movements additionally affect the heat balance on the land surface, since transpiration from stomata usually accounts for a large portion of evapotranspiration (latent heat flux) on surfaces with dense vegetation. The regulation of stomata has therefore been studied extensively to understand their physical functioning

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and physiological responses to the environment (e.g. Kramer and Boyer, 1995; Martin et al., 1999; Hetherington and Woodward, 2003).

In many earlier studies, stomatal conductance was used as a parameter to express the physical effect of stomatal opening and closing on water transfer between the plant and atmosphere. Stomatal conductance of an individual leaf can be directly measured using instruments, such as a steady state porometer, and their responses to the environment have been studied in various plants and climatic conditions. For example, it is known that stomatal conductance generally increases with increasing solar radiation to facilitate entry of CO_2 into the plant body for photosynthesis. In contrast, it generally decreases under increasingly desiccating conditions to reduce water loss from the plant body. These responses of stomatal conductance to the environment vary with plant species and physiological stage (Jones, 1992).

On the other hand, surface conductance (or canopy conductance) has been used as a parameter to express the physical effect of stomatal movements at the canopy scale when the vegetation was regarded as a single object in a big-leaf model. Surface conductance (or canopy conductance) can be estimated easily based on the measurement of heat fluxes on the land surface, and their responses of heat fluxes to the environment have been studied (Takagi et al., 1998; Wever et al., 2002). Since the surface conductance depends on the leaf area index (LAI), it has a disadvantage for annual plants that show large variation in LAI. Therefore, bulk stomatal conductance (mean stomatal conductance in the vegetation canopy) rather than surface conductance is used as a parameter in many micrometeorological and land surface models (Dickinson et al., 1986; Sellers et al., 1986). Bulk stomatal conductance and leaf stomatal conductance are equivalent and offer the advantage of (a) being independent from the LAI, and (b) it is possible to compare them directly. However, bulk stomatal conductance cannot be measured directly and usually its response to the environment has been estimated based on knowledge of leaf stomatal conductance or surface conductance (Raupach, 1995).

Rice (*Oryza sativa* L.) is an important crop worldwide, especially in Asian countries. The responses of leaf stomatal conductance and canopy conductance to the environment in rice are well studied (Oue and Ono, 2000; Yoshimoto et al., 2005). However, the response of bulk stomatal conductance to the environment has not been studied and so the diurnal and seasonal variations are unclear. Since the paddy soils in rice fields are saturated throughout the growing season, soil resistance to evaporation is negligible for latent heat transfer between the ground and atmosphere. This is advantageous for the evaluation of bulk stomatal conductance based on the measurements of heat fluxes.

In this study, we aimed to determine directly the diurnal and seasonal variation in bulk stomatal conductance of rice, in relation to climatic conditions and rice developmental stage. To achieve this, season-long observation of heat fluxes were conducted in paddy rice fields at three experimental sites with different cropping seasons to obtain diverse data. Bulk stomatal conductance was calculated based on observed flux data using a heat transfer model, which expresses the ground and vegetation heat fluxes separately as a SW-type model (Shuttleworth and Wallace, 1985). In addition, variation in bulk stomatal conductance with climatic conditions and rice developmental stage was examined. We determined the common relationship between bulk stomatal conductance and developmental stage in rice for all cropping seasons to make it possible to use the micrometeorological and land surface models with response to rice phenological development.

2. Field experiments

2.1. Site description

Experiments were conducted in commercial rice fields in Miyazaki Plain (Saito), Chikushi Plain (Saga) and Aso Basin (Aso), which were selected as being representative rice-growing areas experiencing a humid temperate climate in Japan. Table 1 lists the location and soil types of the three sites. Rice-cropping seasons differed widely at these sites as outlined in Table 2. The rice cultivar 'Koshihikari' was used, and recommended agronomic and water management practices were followed

Table 1 – Location and soil type at each experimental site

Site	Terrain	Location			Soil type
		Latitude	Longitude	Elevation	
Saito	Miyazaki Plain	32°06.0′N	131°22.7′E	11 m	Gray soil
Saga	Chikushi Plain	33°12.2′N	130°16.8′E	10 m	Gray soil
Aso	Aso Basin	32°56.9′N	131°03.3′E	488 m	Andosol

Table 2 – Cropping season and date of rice development at each experimental site

Site	Cropping season	Date of rice development (days after transplanting)			
		Year	Transplanting	Heading	Maturation
Saito	Early season	2002	18 March	15 June (89)	25 July (129)
Saga	Late season	2002	15 June	27 August (73)	8 October (115)
Aso	Usual season	2003	18 May	18 August (92)	25 September (130)