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Yield components in response to thermal environment and irrigation system in lowland rice in the Sahel

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ABSTRACT

Yield reductions have been widely observed under water-saving irrigation in lowland rice. The yield gap has been related to decreases in the number of spikelets per panicle and decreased spikelet fertility. Since these yield components highly depend on the thermal environment of the meristem which is subjected to changes when a ponded water layer is omitted, the impact of irrigation system on yield components needs to be studied under consideration of temperature at meristem level. Therefore, the objective of this study was to analyze yield and yield components of irrigated rice grown with and without a ponded water layer under consideration of effects of irrigation system on meristem temperature under field conditions. Field trials were conducted on two sites in Senegal, where rice was grown under flooded and non-flooded conditions with six staggered sowing dates between August 2009 and June 2010. Temperature was measured at meristem level and related to leaf area, yield and yield components of three different varieties (i.e. IR64, Sahel202 and N22). Yield reductions under non-flooded conditions were mainly observed in the cold-dry season, whereas slight yield increase were found in the hot-wet season. Among the yield components, reduced number of spikelets per panicle and spikelet fertility accounted for the largest share of the yield gap. Meristem temperature during the night was always lower under non-flooded conditions and the temperature difference between irrigation treatments increased during the cold-dry season. Leaf area per tiller was linearly related to meristem temperature in the observed temperature range, and a linear relationship was found between leaf area per tiller and the number of spikelets per panicle. Furthermore, spikelet fertility increased with meristem temperature between panicle initiation and booting stage. Therefore, lower meristem temperature led to smaller leaf area per tiller, less spikelets per panicle and decreased fertility under non-flooded conditions. Without standing water, the rice plant's meristem will be exposed to lower temperatures during night, which can lead to significant yield reductions in areas where cool nights occur.

1. Introduction

Increasing water scarcity led to the development and introduction of several water-saving technologies in irrigated lowland rice production. The omission of a ponded water layer usually leads to more yield per unit of water applied and therefore an improved field-level water productivity, but even though water can be saved easily, yield reductions are often observed in non-flooded rice fields (Tuong et al., 2005). Reported effects of water-saving irrigation on yield components vary widely. Whereas none of the yield components alone could explain the yield gap between aerobic and flooded rice in experiments conducted in the Philippines (14°11′ N) (Bueno et al., 2010), spikelets per panicles were considered as the most important factor responsible for the yield reductions under aerobic cultivation in experiments conducted in north-east India (25°39′ N) (Patel et al., 2010). For northern China (40°02′ N), a decrease in spikelet fertility with decreasing water input was reported, but results were inconsistent between years and varieties (Bouman et al., 2006). Since the reported effects of water-saving irrigation on yield components appear to be rather contradictory, site-specific characteristics might be of importance. Recently, higher yields observed in the 'ground cover rice production system' (GCRPS) as compared to the traditional paddy cultivation system in a cool climate in central China were related to higher soil temperature under GCRPS conditions and in turn to a larger number of panicles, an increased number of spikelets per panicle, and a

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higher percentage of filled grains (Liu et al., 2013). The formation of yield and its components (i.e. number of panicles per unit area, number of spikelets per panicle, thousand grain weight (TGW) and spikelet fertility) are processes highly dependent on environmental conditions. Although TGW increases with higher radiation during grain filling stage (Yoshida and Parao, 1976), it is probably the yield component, which is least affected by environmental conditions, because grain size is limited by the size of the hull (Yoshida, 1981). However, a high percentage of spikelet sterility is caused by temperatures below 20 °C persisting for a few days at booting or heading and temperatures above 35 °C at anthesis or flowering (Yoshida, 1981; Fageria, 2007). The number of panicles per unit area is largely dependent on tillering performance, which was found to be driven by LAI, probably via the attenuation of light intensity and/or by influencing light quality at the base of the canopy (Zhong et al., 2002). Number of spikelets per panicle has been described to decrease (Yoshida, 1973) and also to increase (Kovi et al., 2011) with increasing temperature, indicating a process not driven by temperature alone. Close correlations between number of spikelets per panicle and dry weight per tiller (Shiratsuchi et al., 2007) or leaf area per tiller (Sheehy et al., 2001; Zhang and Yamagishi, 2010) have been drawn and the relationship was shown to be robust for different planting densities, fertilizer applications and tiller orders. Since number of panicles as well as number of spikelets per panicle have been correlated with leaf growth, which in turn depends strongly on environmental conditions, an environmental effect on these yield components can be established. Leaf growth of rice is enhanced up to a temperature of 30 °C during the day and up to 27 °C during the night, and a positive effect of raised night temperature on leaf growth was even observed during the day (Cutler et al., 1980). Since the rice plant's meristem is below the water surface until booting stage in traditionally flooded fields, water temperature has a larger influence on growth than air temperature (Shimono et al., 2002). When water-saving methods are applied, the meristem is subjected to a change of the thermal environment, since water has a higher heat capacity than air. Even though this aspect could have effects on leaf growth and therefore on panicle number and spikelets per panicle and also directly on spikelet fertility, it has not been considered in literature on water-saving irrigation and its influence on yield and yield components so far. Therefore, the objective of this study was to analyse yield and yield components of rice grown with and without a ponded water layer during different seasons in a highly variable thermal environment under consideration of meristem temperature.

2. Materials and methods

2.1. Site description

Field trials were conducted between August 2009 and October 2010 at two sites belonging to the Sahel station of the Africa Rice Center. Both sites have a typical Sahelian climate with a short rainy season from July to early October, cool nights occurring specially in the cold-dry season between November and February, and high maximum temperatures in the hot-dry season between March and June. In Ndiaye (16°11′ N, 16°15′ W), located in the Senegal River delta, climate is influenced by the Atlantic Ocean, which is about 26 km to the west, whereas in Fanaye (16°32′ N, 15°11′ W), located farther inland in the Senegal River valley, a more continental climate prevails with lower minimum temperatures in the cold season and higher maximum temperatures in the hot season. In Ndiaye, temperature, relative air humidity, solar radiation, and wind speed were recorded with an Onset Hobo© weather station each 20 min. In Fanaye, the same weather parameters were recorded with a Delta-T© weather station in the same intervals

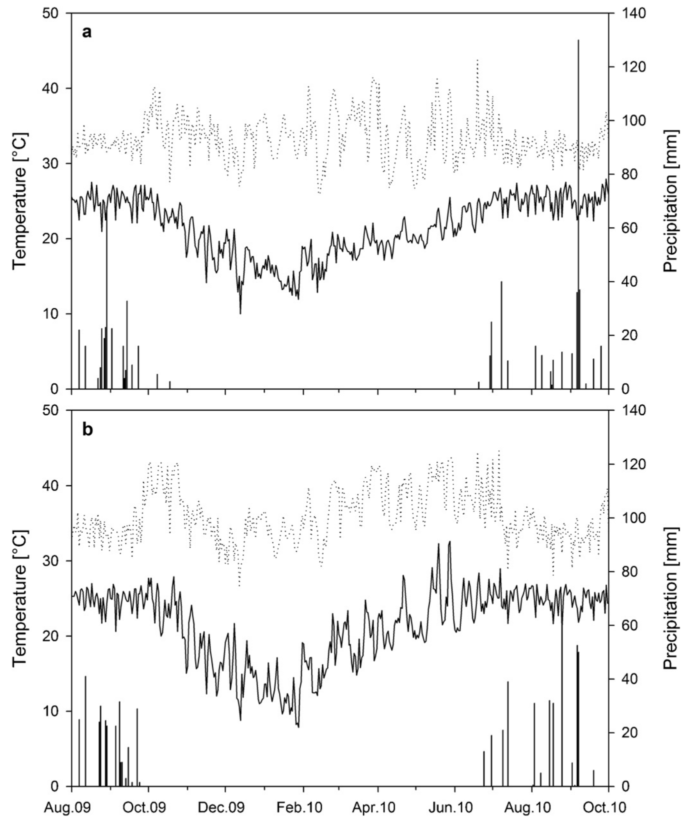

Fig. 1. Minimum and maximum air temperature and precipitation between August 2009 and October 2010 in Ndiaye (a) and Fanaye (b).

(Fig. 1). All sensors were installed close to the experiments, 2 m above the soil. Precipitation was measured at the Senegalese agencies SAED (Ndiaye) and ISRA (Fanaye), which both are located 300 m from the respective experiments. In Ndiaye, soil is characterized as orthothionoc Gleysoil following the FAO soil classification (FAO, 2006) with a texture (0–20 cm) of 16–44–40% sand, silt, and clay (Haefele et al., 2004). The experimental site has a shallow ground water table at about 0.8–0.4 m below the soil surface (de Vries et al., 2010). The soil in Fanaye is classified according to the FAO as eutric Vertisol with 8–28–64% sand, silt, and clay (Haefele et al., 2004). According to de Vries et al. (2010), ground water table at this station is constantly below 3 m.

2.2. Experimental design and irrigation treatments

Rice was sown on 6 bi-monthly staggered dates between August 2009 and June 2010 on both sites (Table 1). Plots of the different sowing dates were located directly next to each other. Each plot consisted of two sub-plots with different irrigation treatments in three replications. Each replication (3 m × 4 m) was bunded separately and had access to the irrigation canal. In order to prevent lateral water flows from the flooded to the non-flooded treatment, sub-plots were separated with a spacing of 10 m. In the flooded

Table 1
Dates of sowing in Ndiaye and Fanaye.

Year	Month	Ndiaye	Fanaye
2009	August	17.08.09	20.8.09
	October	12.10.09	15.10.09
	December	14.12.09	10.12.09
2010	February	15.02.10	11.02.10
	April	12.04.10	19.04.10
	June	14.06.10	17.06.10