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Impact of climatic conditions on rice yield under water-saving irrigation in the Sahel

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Introduction

Since rice production is one of the largest fresh water consumers worldwide, water-saving irrigation methods and reduction of water losses are of special interest in water scarce environments. In Senegal, fuel for water pumps is one of the major expenses in rice production and interest in water-saving irrigation methods is also rising from increasing fuel prices (Krupnik et al., 2010). Different water-saving irrigation methods have been established so far and reported results vary widely from large yield reductions to minor yield increases whereupon the magnitude of yield reduction mainly depends on the severity of drought and the frequency it occurred (Bouman and Toung, 2001). Since the minimum water temperature is usually higher than the minimum air temperature, the water layer buffers low temperature in continuously flooded paddy systems (Yoshida, 1981) and the absence of a water layer under water-saving condition affects the growing point of the plant. In Senegal, climatic conditions are highly variable in the course of the year and three distinct seasons can be described: a hot-dry season from March to July with high maximum temperatures and a high evaporative demand, a short wet season from August to September and a cold-dry season from November to February with low minimum temperatures. The objectives of the study were to analyze the effect of different climatic conditions on yield under flooded vs. water-saving conditions and to determine the seasonal impact on yield losses under water saving irrigation.

Material and Methods

The field experiments were conducted between January 2009 and October 2010 in Ndiaye (16°11'N, 16°15'W), located in the Senegal River delta. The experimental site belongs to the Sahel station of the Africa Rice Center. Rice was sown on 4 bi-monthly staggered dates between January and July 2009 and on 6 bi-monthly staggered dates between August 2009 and June 2010. Two irrigation treatments were established. The flooded treatment was continuously kept under flooded conditions. Water level depended on plant height with approximately 5 cm during early development phases and up to 15 cm after full crop establishment. The water-saving treatment was irrigated until soil saturation on a daily basis until onset of tillering. Afterwards, irrigation water was applied every two to three days until soil saturation. Two rice varieties (*Oryza sativa* L.) were used in 3 replications: IR64, an improved short duration indica variety, as international check variety and Sahel108 (IR13240-108-2-2-3), an improved short-duration indica variety,

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which is most frequently cultivated in the region. For individual irrigation measurements, each variety-plot (3 m x 4 m) was bunded separately and had access to the irrigation canal. In Ndiaye, soil is characterized following the FAO soil classification (FAO, 2006) as orthothionoc Gleysoil 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, which is 0.8-0.4 m below the soil surface (de Vries et al., 2010). Irrigation water input was measured for each variety in each treatment without replication with a v-notched weir. For this, time and water height were recorded while water was passing the weir and the discharged water quantity was calculated using the Brater and King formula (1976):

$$Q = 13.8 \tan(\theta / 2) H^{2.5} \quad \text{(Equation 1)}$$

where Q is the water discharge (cm^3 sec^{-1}), 13.8 is a constant ($cm^{0.5}$ sec^{-1}), θ is the angle of the weir (63.2°) and H is head level (cm) in the notch. For total water input, discharged water was combined with precipitation. Evapotranspiration was measured with 60 cm x 60 cm x 60 cm closed-bottom lysimeters, which were installed in the plots to a depth of 30 cm. Rice, was sown inside the lysimeters with the same spacing like in the remaining plot. For yield determination, hills in a central area of 1.4 m x 2.4 m were harvested in each plot and threshed. Filled grains were separated from unfilled grains and weighed, and grain weight was corrected to 14 % moisture content. Four hills from the corners of the central area were used for yield component determination. Water temperature and meteorological data were recorded in 20 min intervals.

Results and Discussion

Yield of IR64 and Sahel108 varied widely in the course of the year including a complete yield failure after sowing in October. After sowing in October, flowering occurs in the cold season, which is leading to cold induced spikelet sterility. Differences in yield between the flooded and the water-saving treatment, which are shown in Figure 1 as yield penalty, varied widely in the course of the year as well. Consistently over varieties, yield penalty was larger in the hot-dry season and in the cold-dry season and smaller in the hot-wet season.

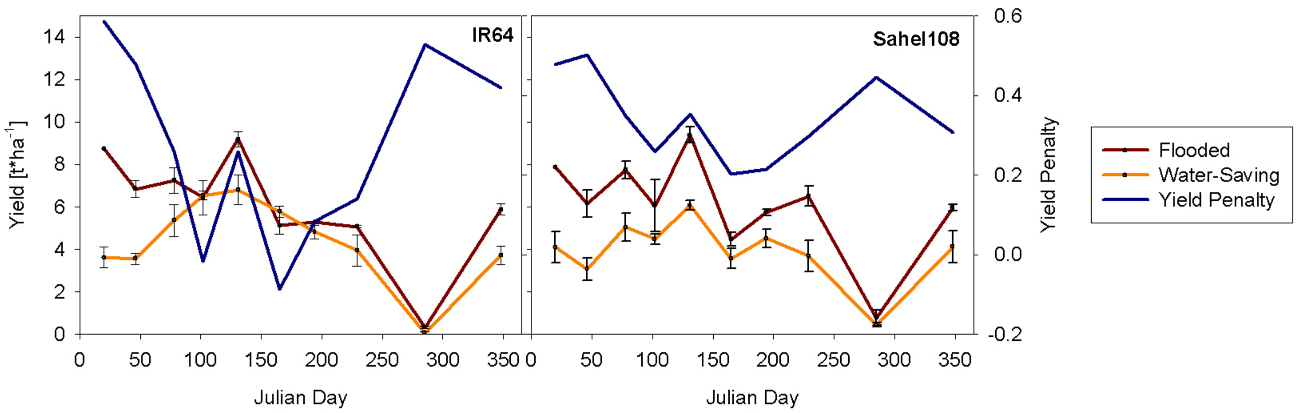

Figure 1: Yield (t*ha^{-1}) of IR64 and Sahel108 for 10 sowing dates under flooded and water-saving conditions. The blue line indicates the yield penalty under water-saving conditions compared to the flooded treatment.

Due to a varying percolation rate, variation in water input was larger than variation in evapotranspiration (Figure 2). Evapotranspiration was lower under water-saving conditions than under flooded conditions, which indicates an effect of drought. Whereas in the two dry seasons evapotranspiration under water-saving conditions was in the range of reference evapotranspiration, it was larger than the reference evapotranspiration in the wet season, which suggests a better water supply in the wet season.

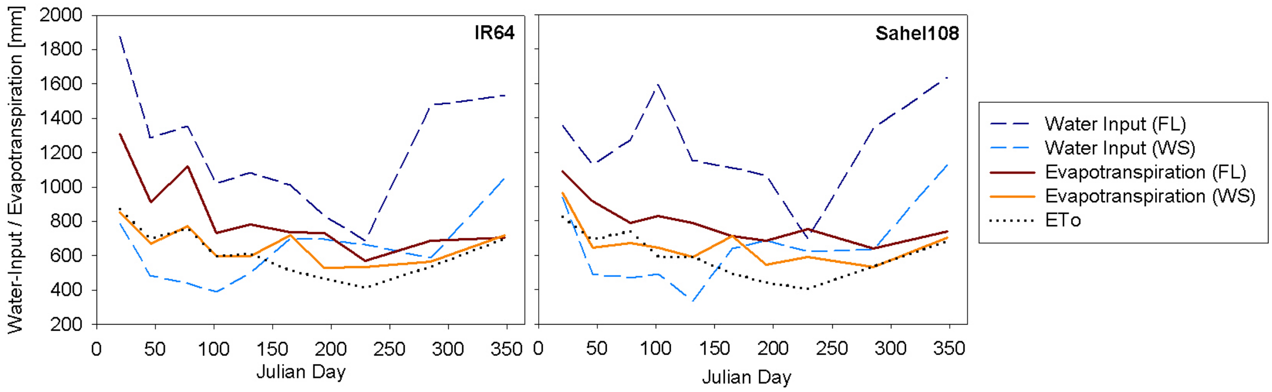

Figure 2: Water input (irrigation + rainfall) and evapotranspiration of IR64 and Sahel108 for 10 sowing dates under flooded (FL) and water-saving (WS) conditions. Dotted line indicates sum of reference evapotranspiration.

During the cold-dry season and the early hot-dry season minimum water temperature was up to 3°C higher than minimum air temperature, whereas differences between minimum water and air temperature became smaller towards the wet-season (Figure 3). The temperature regime directly above the soil surface affects the growing point of the plant during the vegetative stage and later on the panicle formation during the early reproductive stage. Since the growing point of rice under non-flooded conditions is exposed to air instead of water temperature, lower air temperature can lead to a reduced number of spikelet per panicle.

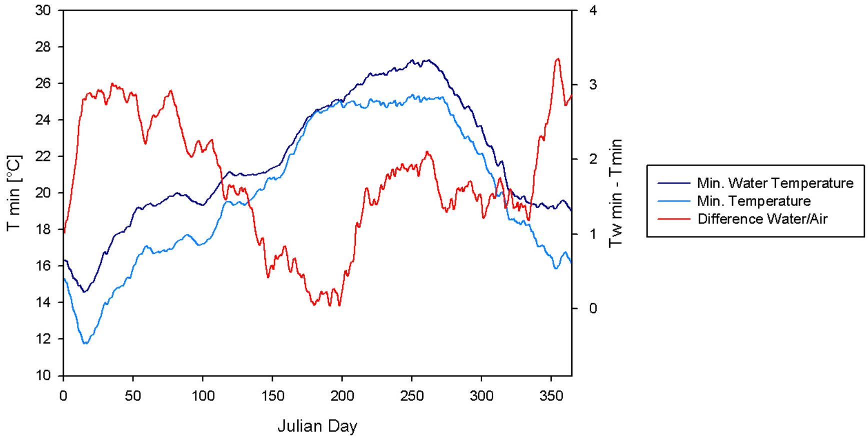

Figure 3: Daily minimum water and air temperature (°C) in the course of the year. Red line indicates difference between minimum water and minimum air temperature.

In order to evaluate the impact of drought and low temperature on the yield penalty under water-saving conditions during different seasons, a principal component analysis (PCA) was performed. Included variables were the yield penalty, the K_c depression, which is the relative reduction of the ratio between actual and reference evapotranspiration and can be used as a measure of drought stress, the reduction of straw weight under water-saving conditions, which is an indicator of stress during the vegetative period, and the reduction of spikelets per panicle as indictor of cold stress due to the absence of a water layer. Figure 4 shows axis one and two of the PCA. Axis one and two explain 76% of the total variance. A high yield penalty was correlated with low minimum temperature in the hot-dry and the cold-dry season. A strong depression of the K_c-value and the reduction of straw weight were correlated with a high ETo in the hot-dry season, whereas the reduction of spikelets per panicle was correlated with a high difference between minimum water and air temperature. Rice sown in April and May (grown between hot-dry and wet season) was included in either hot-dry or wet season, respectively.

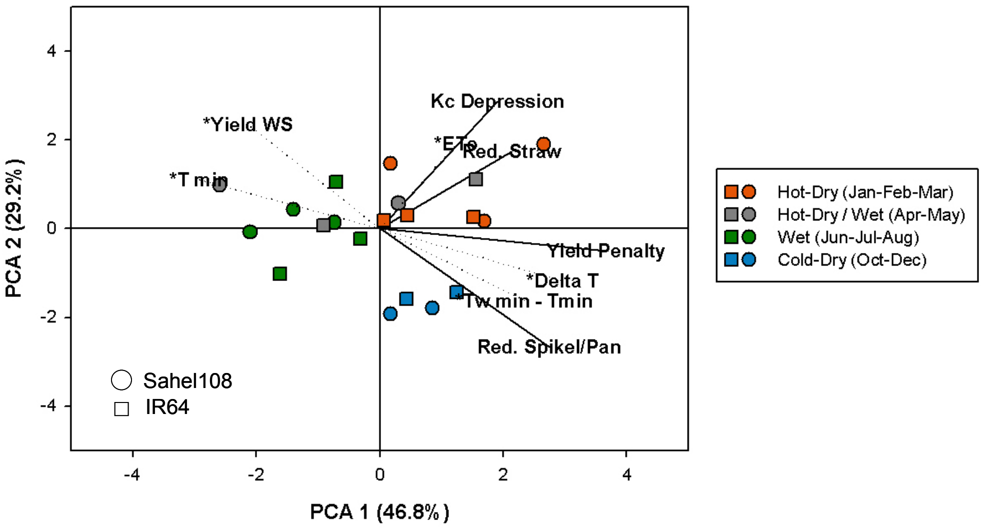

Figure 4: Principal component analysis of 10 sowing dates of IR64 and Sahel108 including yield penalty, K_c depression, reduction of straw weight and reduction of spikelets per panicle under water-saving irrigation in relation to the flooded treatment. Minimum temperature, difference between minimum air and water temperature, air temperature amplitude and reference evapotranspiration as mean values over the growing season and yield under water-saving condition were projected onto the vector subspace of axis 1 and 2.

Conclusions and Outlook

Yield reduction under water-saving irrigation was more pronounced in the cold-dry and the hot-dry season than in the wet season. Whereas plants in the hot-dry season suffered from soil water deficits, low temperature and the absence of a buffering water layer led to yield decline in the cold-dry season. In Senegal, water-saving irrigation technologies are more likely to succeed in the wet season. Rice production without standing water is an option to save irrigation water in periods or regions without high evaporative demand and/or low minimum temperatures.

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