Agricultural impacts of regional variability of the West African monsoon

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Abstract

Agriculture in the Sudano-Sahelian zone is heavily dependent on the seasonal characteristics of rainfall, i.e. onset, length and termination of the wet season, seasonal rainfall totals and intra-seasonal rainfall distribution. This study seeks to characterize components of regional climatic variability and their impact on simulated, attainable, plot-level yields of millet.

First, we will characterize at a regional scale two main events in the seasonal pattern of the monsoon over West Africa by using a daily rainfall dataset over the 1968-1990 period, that is, (1) the "onset" of the summer monsoon characterized by an abrupt northward shift of the ITCZ from 5?N to 10?N around the 24th June, and (2) large and coherent, intra-seasonal rainfall fluctuations at two different spectral windows, between 10 and 25 days and between 25 and 60 days.

Second, we will investigate the impact of these regional phenomena on local crop yields using SARRAH, a crop model simulating water-limited yield, by means of sensitivity analyses. The response of attainable yield (limited by climate and water resources but not mineral nutrition) to sowing date was studied for 19 years of the 1968-1990 period for a 90-day millet crop at Niamey. Yield variability is analysed with respect to the apparent validity of regional (climatic) and local (rainfall events) decision criteria for sowing date, while taking into consideration interannual variability of rainfall and intra-seasonal dry spells. Results indicate that information on regional climate dynamics might help improve crop production locally.

Media summary

By means of sensitivity analyses using a crop model, this study shows how information on regional climate variability might help improve crop production locally in Sahelian area.

Key Words

West Africa, monsoon onset, crop modeling, agricultural impacts, sowing date, intra-seasonal variability.

Introduction

Rural populations are exposed to the impacts of climate variability on agricultural production—the most weather-dependent of all human activities (Hansen 2002). This vulnerability is enhanced for the less economically developed countries in the tropics that, in many cases, are exposed to high variability in climate at different time and space scales. This includes the monsoon system over West Africa and India and the ENSO influence over many other parts of the world (Challinor et al. 2003). This is particularly true for rain-fed agriculture in the Sahel—the only region world-wide where food production per capita has decreased. Staple crop production occupies an important place in governmental policies, and one of the top priorities has become the stabilisation of crop yields (Sivakumar 1988) in the context of the long-term drought of the last decades and the uncertainties of the global climate change (Bazzaz and Sombroek 1996).

In addition to climate variability, farmers are also faced with limited means to control or improve their system because of poorly developed or malfunctioning subsidies, agricultural credit, seed supplies and extension services (Forest and Clopes 1994). Irrigation is only rarely an option and use of fertilizers, mechanized cultivation and other off-farm inputs is low (Ingram et al. 2002). Consequently, the choice of well adapted cultivars, cultural practices and decision criteria for optimal use of water resources and minimised drought risks are crucial for summer monsoon cropping in West Africa (Sivakumar et al. 2000). This requires a good understanding of the seasonal cycle of the monsoon system and its variability.

The aim of this study is to explore if and how improved understanding of the seasonal cycle of rainfall over the whole West Africa can be used for the benefit of local crop production in a typical Sahelian area.

Methods

The objective of this study is twofold. First, by using daily rainfall data, we characterize at regional scale two main events in the seasonal evolution of the monsoon over West Africa, that is, (1) the real 'onset' of the summer monsoon (Sultan and Janicot 2003) with major changes in the atmospheric circulation over West Africa, and (2) large and coherent rainfall fluctuations at intra-seasonal time-scale at two different spectral windows, between 10 and 25 days and between 25 and 60 days (Sultan et al. 2003).

Second, we investigate the impact of these regional phenomena on local crop yields using SARRAH (Dingkuhn et al. 2003), a crop model simulating water-limited (attainable) yield. Sensitivity experiments are presented to document the response of potential yield to sowing date for millet at Niamey over the 1968-1990 period. Three different scenarios were conducted to simulate attainable yield:

- (1) using a typical threshold method for sowing on the basis of local rainfall based decision rules
- (2) using regional monsoon onset as local sowing date
- (3) using the ideal sowing date from a hydrological and climatic point of view.

The last scenario is a control in which for each year the sowing date is identified that provides the highest attainable yield, based on daily simulation runs from the beginning of May to the end of July. Note that this date may not be ideal since it does not take into account nutrient dynamics, pests and diseases, or labour availability.

This study shows the analysis of variability of attainable yield obtained from these three scenarios in respect to regional (climatic) and local criteria for the choice of the sowing date, while taking into account the role of interannual and intra-seasonal variability of rainfall (Sultan et al. 2004).

Results

In coherence with previous findings (Sultan et al. 2003; Sultan and Janicot 2003), we found that the onset of the summer monsoon is linked to an abrupt latitudinal shift of the tropical rainy belt around 24 June from a quasi-stationary location in Guinean Africa to another quasi-stationary location in Soudano-Sahelian Africa. We also found intra-seasonal variability of convection over the Sahel at two main time-scales, around 15 days and 40 days. The latter low-frequency variability is dominated by a recurrent dry spell occurring in mid-August (mean: 12 August), and whose severity varies from year to year.

Sensitivity analyses on the yield of millet in Niamey with the crop model SARRAH indicated a strong impact of regional scale monsoon dynamics at the plot level. It was shown that, from a climatic and hydrological point of view, information of the onset date of the summer monsoon might contribute to a better choice of the sowing date although these dates need to be evaluated comprehensively from an agronomic and socio-economic point of view. Indeed, the onset of the summer monsoon (mean: 24 June) is close to the 'ideal' sowing date (mean: 22 June) at Niamey. Simulated yields were much higher for these dates than for those identified with the traditional rule based on local rainfall (Figure 1).

Figure 1 compares attainable yield obtained by the traditional threshold method (in white) and that obtained with the regional onset date of the monsoon (in black), expressed as percentage of maximal yield obtained in the control experiment using the 'ideal' sowing date. The regional criterion increases attainable yield; it exceeds 75 % of maximal yields in 14 out of 19 years, as compared to only 7 years with the threshold method (Table 1). On average, the regional criterion gave 75% and the threshold method gave 56% of maximal yield. The latter was associated with a stronger interannual variability (variation coefficient of 64%), nearly twice that of the local threshold rule. In years with very low attainable yields (<25% of max.) using the threshold method, sowing was either far too early (5 years of 19) or too late (e.g. 30 July in 1971). There may thus be a potential to improve local, attainable, millet yields, and reduce their inter-annual variability, by taking into account the regional onset of the monsoon, thus avoiding excessively early sowings.

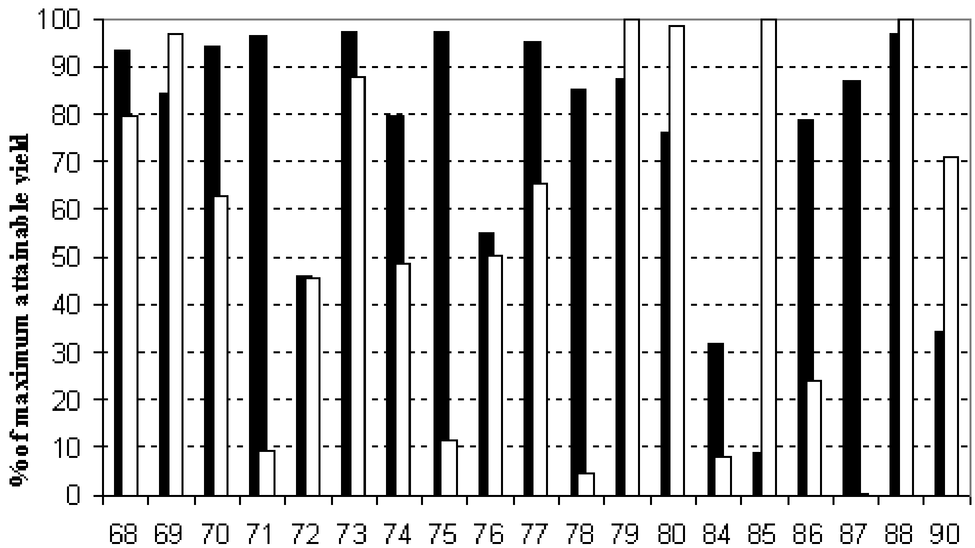

Figure 1. Attainable yield simulated using the threshold method (white) and considering the monsoon onset as the sowing date (black). The yield is expressed in percentage as the ratio to the maximum yield of the year obtained with the ideal sowing date.

The simulations also indicated that low attainable yields simulated with the criterion of regional monsoon onset were generally due to intra-seasonal dry spells, which had differential impacts depending on the phenological stages of the crop affected. Indeed, the dry spells controlled by the 40 days intra-seasonal variability of the monsoon have a strong impact on yield when they happen during the most sensitive period of crop development, namely, the reproductive phase around flowering. In the latter case, the crop may produce a lot of biomass but is unable to convert it into grain.

	Regional criterion	**Local criterion**
Mean	75%	56%
Standard deviation	26%	36%
Coefficient of variation	34%	64%

Table 1?: Mean, standard deviation and coefficient of variation of the attainable yield over the 1968-1990 period by using the regional and the local criterion for the choice of sowing date. The yield is expressed in percentage as the ratio to the maximum yield of the year obtained with the ideal sowing date.

Conclusion

We presented a preliminary study on analysis of West African monsoon dynamics at regional scale with their simulated impacts on attainable millet yield at the plot scale at a representative site in the Sahel. It was shown that, from a climatic and hydrological point of view, information of the onset date of the summer monsoon might contribute to a better choice of the sowing date, although these dates need to be evaluated comprehensively from an agronomic and socio-economic point of view. Indeed, simulated yields were much higher for these dates than for those identified with the traditional rule based on local rainfall. The results have also indicated that (1) drought spells within the rainy season belonging to the intra-seasonal variability of the monsoon may or may not have a strong yield impact depending on the phenological stages of the crop affected, and (2) regional-scale rainfall anomalies filter through to the plot level, and therefore bear potential for regional predictions and recommendations.

However, at this stage the results are based only on numerical computations with a crop model that simulates water-limited yield. The simulations must be validated with observations collected in cultivated areas to verify the relevance of the attainable yield concept used in this study for on-farm conditions in the Sahel, and to evaluate the importance of other environmental constraints that were not simulated, such as mineral nutrition and weed competition. It is important to extrapolate these results to other locations in West Africa and to other crops and cultivars, in particular the photoperiod-sensitive, traditional cultivars of sorghum and millet (Vaksmann et al. 1996) that might respond differently to variations in rainfall patterns. The perspective of intensive, multi-disciplinary observations planned by the AMMA project (African Monsoon Multidisciplinary Analysis ; http://medias.obs-mip.fr/amma/) and its large spectrum of covering scales, ranging from local to regional to sub-continental to global, will offer a great opportunity to further develop the approach proposed in this paper, particularly with respect to model validation and extrapolation.

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