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RAINFALL RISK AND 'RESPONSE FARMING': USING RAINFALL ANALYSIS, SIMULATION MODELING & GIS TO IMPROVE AGRICULTURAL DECISIONS IN MALI

How is production of food crops affected by the high degree of climate variability in the Sahel? What aspects of seasonal rainfall are most determinant of crop performance? How does the impact of rainfall variability relate to other environmental factors in shaping yields? Can advances in rainfall predictions and simulation modeling help mitigate farmers' exposure to climate risk?

Downloading data from Madiama rainfall station

The Sahel region of West Africa is plagued with extreme rainfall variability and chronic food insecurity, conditions that have worsened since the early 1970s. There is a pressing need to identify and promote dry land agriculture practices that better utilize the available rainfall. An understanding of the intimate relationships between the weather, soils and crops is an essential step for designing appropriate strategies to improve food production. But efforts by agricultural scientists and farmers to determine optimal farming technologies and cropping systems have been hindered by the complex nature of the combination of seasonal rainfall variability, crop cultivars, farming practices and soil types.

However, today we can combine historical records, research tools and computing power to sort through these complexities and provide farmers with information that can help them make better crop management decisions. Assessment of weather, soils, and management scenarios using computerized tools can help in screening suitable technologies. This will enable local farmers to move from a low-productivity risk-aversion orientation to a tactical 'response' approach that optimizes production potential while also reducing their vulnerability to climatic extremes.[1]

[1] Stewart, J.I. 1988. *Response Farming in Rainfed Agriculture.*, The WHARF Foundation Press.

ABOUT SANREM CRSP

SANREM's mission is to assist in the analysis, creation and successful application of decision support methods, institutional innovations and local capacity approaches to support participatory sustainable agriculture and natural resource planning, management and policy analysis at local, municipal, provincial and national levels.

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In this study, analyses of historical rainfall records are combined with GIS and biophysical modeling of soil water balance and crop production to predict performance of millet cultivars in Mali. The research improves previous efforts to apply rainy season predictions to agricultural decisions in the Sahel region, by integrating soils and crops information and by using crop simulation modeling[2]. For two data sets defined by (early or late) rainfall onset date, the simulated crop yields, average water stress, and overall stress indices relative to yield potential have been computed and mapped. Research findings indicate that probability analysis and simulation modeling can be used to minimize agro-climatic risk.

BACKGROUND

The commune of Madiama is situated about 25 km from the city of Djenné, in the Niger Delta region of Mali. The area is characterized by a short rainy season (3 to 4 months), considerable variability in rainfall from year to year and place to place, with high levels of evapo-transpiration, that further limit rainwater availability for crops and pastures. For the period between 1950 and 2000 the mean annual rainfall was 544 mm, with the lowest value being 275 mm in 1987 and the highest 914 mm in 1957.

Farmers consider rainfall as the principal factor determining crop production. Both deficit and excess of rainfall can have deleterious effect on crop performance. Low yields are often related to a late start of rains or a drought period after planting, but too much rain in late July and early August can also impede grain development. In this uncertain environment, where crop performance varies greatly from season to season, farmers' management strategies aim to minimize risk rather than maximize yields. Production systems center on cultivation of various fields and soil types, planted with local varieties of millet, occasionally intercropped with cowpeas or peanuts, with a low and uneven application of organic matter.

METHODOLOGY

Long-term and seasonal analyses of rainfall
Historic daily weather data (solar radiation, rainfall, air temperature) were obtained from the National Meteorological Service of Mali. An automatic weather station with data logger was installed in Madiama in June1999. Individual rain gauges are also installed in each of the 10 other villages of the commune. These weather data have been used for the rainfall analyses and simulation modeling.

Based on an analysis of linear relationships, 3 sets of parameters were identified for the 1970-2000 record: a) the dates of onset and end of rains[3]; b) the length of the rainy season (that is the number of days from the date of onset to the final rain date; c) the seasonal amount of rainfall, that is the total rainfall from onset to end of rains. Also, a dekadal (every ten-day) reliability analysis was done on the basis of daily rainfall records, and statistical trends plotted throughout each year.

Simulation modeling and agroclimatic assessment
CropSyst is a multi-year, multi-crop, daily time-step simulation model developed to serve as an analytical tool for investigating the effect of cropping systems management on crop productivity in relation to environmental patterns such as soils and weather.[4] The model simulates the soil water budget, soil-plant nitrogen budget, dry matter production, yield, etc. It was used to assess the growth environment of a 90-day local millet variety, known as *Sagnori*, and the impact of nitrogen fertilization in years of early and late onset of rains. A millet monoculture was simulated using two fertilization levels, one representing traditional low input system and the other representing an improved systems.

Simulation and output analysis
After calibrating the model for the millet cultivars, the databases for soils, weather, and crops have been combined to simulate soil water balance and crop yield potential in years of early and late rain onset dates as a function of soil types and nitrogen input levels. The outputs of the soil water budget and the crop production functions obtained from the simulation were used to determine the development and the environment of the Sagnori millet variety.

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[2] Sivakumar, M.V.K. 1990. Exploiting Rainy Season Potential from the Onset of Rains in the Sahelian Zone of West Africa. Agriculture and Forest Meteorology, 51, pp. 321-332.

[3] The date of onset of the rains is considered as the first day after June1[st] when stored soil water equals at least 40 mm and/or when rainfall accumulated over 3 consecutive days is at least 20 mm and if no dry spell during the following 30 days exceeds 7 days. The date of end of the rains is considered as the day after September 1[st]after which no rain occurs over a period of at least 20 days.

[4] Stöckle, C.O, S.A. Martin, G.S. Campbell, 1994. CropSyst, a Cropping System Simulation Model: water/nitrogen budgets and crop yield. *Agricultural Systems*, 46, pp. 335-359.

Table 1: Variability of rainy season rainfall characteristics, including date of onset, rainfall amount and duration of season (1970-2000): range of values (*median*)

No. of years	Type of year	Onset date	Amount (mm)	Duration (days)
31	All	June 6-July 30 (*June 27*)	274-801 (*502.5*)	61-40 (*98*)
16	Early onset	June 2 -June 26 (*June 11*)	406-801 (*529*)	93-140 (*105*)
15	Late onset	June 28-July 30 (*July 8*)	274-617 (*432.5*)	61-98 (*74*)

The biophysical indicators used were:

- ✓ The average water stress index (AWSI) is the ratio between actual transpiration and maximum (potential) transpiration during the crop growth cycle. This is used as indicator of plant response to its environment and can help in the choice of crops or soils best suited to local conditions.
- ✓ Crop yields and overall stress index (OSI) were calculated in reference to yield potential permitted by different soils under low and optimum nitrogen input levels. The OSI integrates light, temperature, water and nitrogen stress indices and is an indicator of the risk of growing a certain crop in a given environment.

RESULTS/DISCUSSION

Analysis of long-term and seasonal rainfall patterns

A trend of declining rainfall and increasing inter-annual variability over the last three decades is evident:

- ✓ For the period between 1950 and 1969, annual rainfall averaged 636 mm, with percentage deviation from the mean only around 10%.
- ✓ For the period between 1970 and 2000 annual rainfall averaged 482 mm, with percentage deviation from the mean reaching 50% in 1987.

For the last 31 years, rainfall is likely to be equivalent or inferior to the mean of 482 mm in about 4 years out of 10. The probability analysis of monthly rainfall for this period indicates that in 7 years out 10 there will be no rains in May and in October.

The 31-year record shows a great deal of variability in onset date, which may occur as early as June 6 or as late as July 30, a span of 55 days. The duration of the season is equally variable, ranging between 60 and 140 days (Table 1). The data for the 1970-2000 period shows a strong correlation between onset dates on the one hand and rainfall amounts and duration of the rainy season on the other (Figures 1 & 2).

For analytical purposes, the last 31 years were divided between "early onset" years, with rains beginning before the median onset date June 26, and "late onset" year, with rains beginning after June 26. Early onset years have a higher median rainfall quantity (529 mm) than late onset years (432.5 mm) and have also a longer median duration of the season (105 days) than late onset years (74 days) (Table 1).

Simulation Modeling and Agroclimatic Assessment

Simulation modeling can be used as a tool to evaluate the suitability of cropping systems and technologies that can be recommended in years of early or late onset of the rains. The outputs from the soil water budget and crop production modeling were used to compute the following indicators: a) Crop Yields; b) Average Water Stress Index (AWSI); and c) Overall Stress Index (OSI). These indicators were then mapped to illustrate their spatial distribution as a function of soil type.

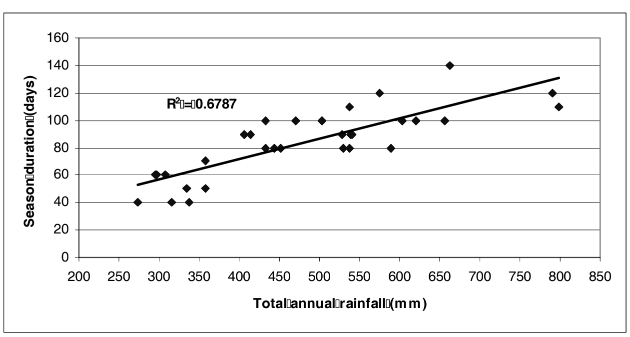

Figure 1. Duration of rainy season vs. total annual rainfall

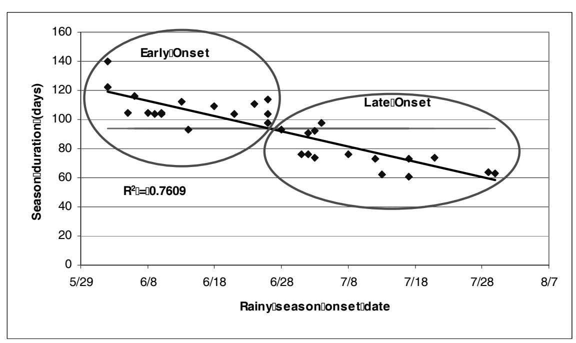

Figure 2: Onset date vs. duration of the rainy season

Yields relationships to onset dates and nitrogen inputs

- ✓ Yields decreased with delayed rain onset regardless of input levels. But fertilization level was found to affect yields more significantly in early onset years than in late onset years. Soils with higher water holding capacity gave higher yields levels regardless of input levels or date of rain onset. On the other hand, shallow soils (< 40 cm deep) have shown total crop failure (less than 100 kg/ha) regardless of input level or onset date.

- ✓ Yields were significantly more affected by rain onset date than nitrogen input. Without fertilization, early onset years have a 56% probability of a good crop (>800 kg/ha), with only 19% chance of failure (<400 kg/ha). In late onset years, there is only 14% of chance of good crop against 57% chance of crop failure. Fertilization only increased the probability of a good crop in late onset years to 28%, while the probability of failure remained high (51%).

AWSI relationship to onset dates and crop yields

- ✓ The Average Water Stress Index (AWSI) was computed to better understand the relationships between crop, weather and soil in the study area. Regardless of soil type and input levels, early onset dates with higher amounts of rainfall have lower stress levels compared to late onset dates. The AWSI rose with delay in rain onset and with greater nitrogen levels, particularly when plant requirements for water were higher.

OSI relationships to onset dates, nitrogen inputs and crop yields

- ✓ The OSI allows one to choose the most suitable soil type in early or late onset years. Overall, OSI and risk levels increased with delay in rain onset. In late onset years, soils that have only average water holding capacity have higher OSI than in early onset years. But soils with high water holding capacity are not suited to millet in early onset years because water logging, higher humidity, lower radiation and lower temperatures will delay crop development and growth.

CONCLUSION

Analysis of the last 31-year rainfall years of the study region confirms that a strong relationship exists between the date of onset and the duration of the rainy season. Earlier onset is associated with longer duration and greater amount of total seasonal rainfall. Findings also reveal that there is a relationships between onset date, agroclimatic indices, (water stress and overall stress), and crop yields. In a late onset scenario, water stress indices increase and crop yields decrease, regardless of fertilization levels.

The association of delayed onset and drought is nothing new for local farmers, who empirically assess the nature of the upcoming season on the basis of the date of onset. When the rains are late, they may respond by planting shorter duration varieties and/or enacting water conservation practices. But farmers may be less aware of how they might benefit from increased fertilization and other management options in years of early onset.

Analyses of soils, weather, crops and management databases in association with simulation models and GIS can generate insights about what technology or cropping system can enable farmers to make optimal use of the environment and the resources at hand. Another potential application is to provide plant breeders with a better representation of the situation actually faced by farmers for whom breeding programs are undertaken.

This brief draws from a paper by Oumarou Badini and Lassana Dioni entitled "Application of Rainfall Analysis, Biophysical Modeling and GIS to Agroclimatic Decision Support in Madiama Commune, Mali (West Africa)." and presented to the SANREM CRSP Research Scientific Synthesis Conference, November 28-30, 2001, Athens, Georgia. PDF versions of individual papers presented at the conference can be downloaded from: http://www.sanrem.uga.edu.

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