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Effects of climate variability and climate change on crop production in southern Mali

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ABSTRACT

In West Africa predictions of future changes in climate and especially rainfall are highly uncertain, and up to now no long-term analyses are available of the effects of climate on crop production. This study analyses long-term trends in climate variability at N'Tarla and Sikasso in southern Mali using a weather dataset from 1965 to 2005. Climatic variables and crop productivity were analysed using data from an experiment conducted from 1965 to 1993 at N'Tarla and from a crop yield database from ten cotton growing districts of southern Mali. Minimum daily air temperature increased on average by 0.05 °C per year during the period from 1965 to 2005 while maximum daily air temperature remained constant. Seasonal rainfall showed large inter-annual variability with no significant change over the 1965–2005 period. However, the total number of dry days within the growing season increased significantly at N'Tarla, indicating a change in rainfall distribution. Yields of cotton, sorghum and groundnut at the N'Tarla experiment varied (30%) without any clear trend over the years. There was a negative effect of maximum temperature, number of dry days and total seasonal rainfall on cotton yield. The variation in cotton yields was related to the rainfall distribution within the rainfall season, with dry spells and seasonal dry days being key determinants of crop yield. In the driest districts, maize yields were positively correlated with rainfall. Our study shows that cotton production in southern Mali is affected by climate change, in particular through changes in the rainfall distribution.

1. Introduction

Since the early 1990s the Intergovernmental Panel for Climate Change (IPCC) has provided evidence of accelerated global warming and climate change. The last IPCC report concludes that the global average temperature in the last 100–150 years has increased by 0.76 °C (0.57–0.95 °C) (IPCC, 2007). Finding evidence of global trends in rainfall is complex because of large regional differences, gaps in spatial coverage and temporal shortfalls in the data. Rainfall generally increased over the 20th century in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean region, southern Africa and parts of southern Asia (IPCC, 2007). Furthermore, there is evidence for increases in the frequency of both severe droughts and heavy rains in many regions of the world. Climate change due to greenhouse gas emissions is expected to further increase temperature and alter precipitation patterns. All 21 General Circulation Models (GCMs) used by IPCC predict a temperature increase in sub-Saharan Africa in the order of 3.3 °C by the end of the 21st century. With regard to predicted changes in rainfall amounts in sub-Saharan Africa, the uncertainty is considerably greater and in many instances models do not agree on whether changes in rainfall will be positive or negative (Cooper et al., 2008).

Rainfed agriculture produces nearly 90% of sub-Saharan Africa's food and feed (Rosegrant et al., 2002), and is major livelihood activity for 70% of the population (FAO, 2003). This agricultural sector is negatively affected by climate variability, particularly through heat waves, droughts, floods, and other extreme weather events. Overall, the success or failure of crop production under rainfed conditions in Sudano-Sahelian West Africa is strongly linked to rainfall patterns (Graef and Haigis, 2001).

In West Africa, a combination of external and internal forces makes the climate of the region one of the most erratic in the world (Zeng, 2003). Annual cycles of rainfall are strongly determined by the position of the inter-tropical convergence zone (WCRP, 1999).

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Many studies have characterized the rainy season in West Africa; most of them were based on decadal, monthly or total annual rainfall analysis (Ati et al., 2002; Nicholson, 1980; Sivakumar et al., 1984), while others studies described the start and end of rainy season (Diop, 1996; Dodd and Jolliffe, 2001; Omotosho et al., 2000; Stern and Coe, 1982). A good understanding of seasonal variability patterns is of critical importance because of the highly unstable onset of the rainy season and the high frequency of dry spells. The last century's climate in Sudano-Sahelian West Africa was marked by high spatial and temporal variability and by alternations between dry and wet seasons (Servat et al., 1998). A review by Traoré et al. (2007) of current knowledge on the regional climate in Sudano-Sahelian West Africa revealed that rainfall remains unpredictable. This rainfall unpredictability is a major constraint for farmers who have to plan the start of the cropping season (Piéri, 1989). The first rains are not always followed by the full start of the monsoon (Sultan and Janicot, 2003), dry spells can occur afterwards, i.e. during the early stages of the crop growth so that seeds may not germinate properly or germinated plants may die off. However, if sowing is delayed, the land may be too wet to till.

Southern Mali occupies 13.5% (approximately 160.825 km^2) of the Malian territory. It represents 50% of the cultivable lands of the country and holds 40% of the Malian population. In southern Mali agricultural activities play an essential role in supplying food to the country; they represent 45% of the country's income (Deveze, 2006). Most people in the region are likely to be vulnerable to climate variability (Sivakumar et al., 2005). Hence, it is imperative to better quantify climate variability and change and their effects on crop production. Several studies analysing long-term relationships between climate and crop yields have been published recently (Kucharik and Serbin, 2008; Lobell and Burke, 2008; Lobell et al., 2008; Lobell and Field, 2007), but none of these focused on West Africa.

We analysed long-time series of weather data recorded in southern Mali, and crop yield data from an experiment at the Research Station of the Institut de l'Economie Rurale at N'Tarla and from farmers' fields in ten districts in southern Mali. The objectives of this study are therefore: (i) to quantify possible changes in climate and crop production over 30 years in southern Mali and (ii) to quantify the effect of annual climate variability and change on crop production.

2. Methods

2.1. Study area and source of data

The climate in southern Mali is typical of the Sudano-Sahelian zone. Average long-term annual rainfall is 846 ± 163 mm at N'Tarla (12°35′N, 5°42′W 302 m.a.s.l.) and 1073 ± 187 mm at Sikasso (11°35′N, 5°68′W 374 m.a.s.l.). The rainy season extends from May to October and the seasonal average temperature is 29 °C. During the dry season (November–April) the temperature and saturation vapour deficit increase and crop production is impossible without irrigation (Sivakumar, 1988).

The most common farming systems in the region are extensive mixed agrosylvo-pastoral systems, focused around cotton (*Gossypium hirsutum* L.) – the main cash crop – in rotation with cereals – sorghum (*Sorghum bicolor* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.) R.Br.), maize (*Zea mays* L.) – and legumes – groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* (L.) Walp.). Cotton and to a lesser extent maize, receive nutrient inputs in the form of organic manure and/or chemical fertilizer, as well as pesticides. Other cereal crops seldom receive any fertilizer. As a result, soils are often mined and soil organic matter contents are declining (Piéri, 1989). Cattle, goats and sheep are the main livestock species. Agro-pastoralists generally practice sedentary farming, although due to large herd sizes and the lack of feed resources, transhumance is practiced in the dry season.

2.2. Climate data

The meteorological data used for the climate analysis in this study were recorded at the meteorological stations of N'Tarla (12°35′N, 5°42′W 302 m.a.s.l.) and Sikasso (11°35′N, 5°68′W 374 m.a.s.l). The database contained long-term (from 1965 to 2005) records of daily rainfall and minimum and maximum temperatures. Daily minimum and maximum temperature were averaged over the rainy season to represent the seasonal temperatures. For the districts, we used the annual rainfall data as they were recorded at the different districts with rain gauges.

2.3. Long-term crop experiment

An experiment was conducted from 1965 to 1993 at the N'Tarla agricultural research station (12°35′N, 5°42′W 302 m.a.s.l.) to determine the long-term impact of cotton-based cropping systems on soil fertility (IRCT, 1969). The trial was set up according to a Fisher block design with three crops (cotton, sorghum, groundnut) as part of a rotation, four fertilization treatments and four replications. Initially, a 3-year crop rotation cotton–sorghum–groundnut was used, from 1968 the crop rotation was cotton–sorghum–groundnut–sorghum and in 1976 returned to the 3-year rotation cotton–sorghum–groundnut. At the start of the experiment, the four fertilization treatments were: an unfertilized control, application of manure, application of mineral fertilizer and the combined application of manure and mineral fertilizer. The fertilizer treatments were modified over time, with the aim to limit soil fertility decline. In the first phase (1965–1979) of the experiment, mineral fertilizer and manure (9 t DM ha^{-1}) were applied only to cotton. From 1980 onwards, mineral fertilizer was allocated to the three crops and manure to cotton (6 t DM ha^{-1}) and sorghum (3 t DM ha^{-1}). Mineral fertiliser was then also applied in the control treatment. Weed and pest control were carried out on all treatments according to the standards recommended by the local agricultural research institute (IER/CMDT/OHVN, 1998).

The soils of the experimental site are highly weathered and classified as Lixisols (FAO, 2006). They have a sandy-loam texture (<10% clay) at the surface, but are richer in clay with depth (30% at 60 cm depth). Soil organic carbon content is low (0.3%), pH is around 6 and CEC is less than 3 cmol (+) kg^{-1}. They are typical soils for the region.

For the analysis of impacts of climate variability and change on crop production, we used only the crop yields of the treatment with the combined application of manure and mineral fertilizer. Since in this treatment there was no significant trend in soil carbon over time, we did not expect soil carbon or soil fertility in general, to have a strong influence on trends in crop yields. We, therefore, assumed that water was the main limiting factor. On the other hand, to evaluate the long-term effects of soil fertility on crop production, the crop yields in the control treatment were used.

2.4. Crop yields from farmers' fields

Crop yield data from ten cotton growing districts of southern Mali (Fig. 1) were obtained from the Malian cotton company (Compagnie Malienne pour le Développement des Textiles). From the available data, a database was developped with average yields at district level for cotton (1974–2005) and maize (1994–2005) together with the corresponding annual rainfall in the districts to evaluate yield-rainfall relationships. Yields from the database