



Cotton as an entry point for soil fertility maintenance and food crop productivity in savannah agroecosystems–Evidence from a long-term experiment in southern Mali



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ABSTRACT

Given the scarcity of manure and the limited land available for fallowing, cotton cultivation with its input credit schemes is often the main entry point for nutrients in cropping systems of West Africa. In an experiment carried out during 25 years in southern Mali, the crop and soil responses to organic fertilizer (=OF), inorganic fertilizer (=IF), and a combination of both (=OIF) were quantified and compared to a control treatment for a typical cotton-sorghum-groundnut rotation. From 1965 to 1979 (15 years, period 1), fertilizers were only applied on cotton and the control treatment was not fertilized. From 1980 to 1989 (10 years, period 2), the amount of manure applied was split between cotton and sorghum, and inorganic fertilizers were applied to the three crops. Inorganic fertilizers were also applied to plots with cotton and sorghum that were previously unfertilized control treatments.

In favorable rainfall seasons maximum yields of fertilized treatments reached ca. 3.5 t ha⁻¹ in the case of cotton and groundnuts, and ca. 2 t ha⁻¹ in the case of sorghum. During period 1, cotton yields were steady (ca. 1 t ha⁻¹) when no fertilizers were added. Cotton yields were 20% higher in the OF and OIF treatments than in the IF treatment. Sorghum and groundnut benefited from residual effects of fertilizer application on cotton leading to a 200% and 50% yield increase respectively compared to the control treatment. During period 2, yields of the three crops were similar across fertilized treatments. Groundnut yields in the OF treatment, and cotton yields in the OF and IF treatments were respectively 45%, 30% and 20% significantly higher than those in the respective control treatments. No added benefit on crop yields was observed from the combined use of inorganic and organic fertilizer. Soil nutrient contents (SOC, N, P, K) did not significantly change in any of the treatments after 25 years. Soil pH decreased in treatments receiving inorganic fertilizer.

Despite low level of soil organic matter, crops responded to organic or inorganic fertilization and crop productivity over time was mostly influenced by the interaction between fertilization and rainfall variability. Our results highlight the role of cotton in West African landscapes as an entry point of nutrients via fertilization, which impacts positively on the productivity of the other crops in the rotation. Credit schemes by the cotton company for farmers to purchase fertilizer to which they would otherwise not have access are thus crucial for sustained crop productivity.

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1. Introduction

The production of cotton (*Gossypium* spp.) is one of the major economic activities in many countries of West Africa, representing up to 75% of the value of agricultural exports of countries, such as Côte d'Ivoire, Benin, Burkina Faso and Mali (OCDE, 2006). Deregulation of production and marketing and the dismantling of national

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commodity boards to support the cotton industry, in combination with severe fluctuations in the international price of fibers have led to a huge decrease in the areas under cotton during the last decade (ICAC, 2013). In many regions of West Africa food crops such as maize or sorghum, whose prices are becoming more attractive on the market, are increasingly replacing cotton on the land cultivated by smallholder farmers (FAO, 2014; Laris et al., 2014). In 2012, West African countries produced less than 5% of the global cotton production (ICAC, 2013). This poses a major threat to the sustainability of the cropping systems, since cotton is often the sole entry point of inorganic fertilizers into the farming system, thanks to the pre-financing input schemes of the cotton industry. The practice of fallow or the use of animal manure, i.e. traditional ways of maintaining soil fertility, are less and less feasible in the face of rural population growth and increasing ratios of cropland-to-grassland (Andrieu et al., 2014). Furthermore, under the current scenario of increasing food prices the reduction in the areas under cotton is likely to continue in West Africa.

It has been repeatedly claimed that food crops in rotation with cotton benefit from the residual effect of inorganic fertilizer applications to the cotton crop (FAO, 1983; Pouya et al., 2013). Moreover, smallholder farmers receiving fertilizers on credit from the cotton industry often use part of them on food crops (Ramisch, 2005). The transfer of fertility from the cotton crop to subsequent crops takes place through two major mechanisms: (1) part of the nutrients taken up by cotton (and weeds) and contained in the biomass not exported out of the field returns to the soil and becomes available to subsequent crops through decomposition of crop residues and roots, and (2) part of the applied fertilizer that is not released in a soluble form readily available to the cotton crop remains in the soil; this is particularly the case for phosphorus (P) in inorganic fertilizers or for nitrogen (N) and P applied with organic materials. Depending on the nature of the nutrient, its source and the environment, including the type of soil, such nutrients may become more or less available to subsequent crops (Bado et al., 2012; Corbeels et al., 1998; Zhou et al., 2014).

The balance between these various mechanisms regulates both current productivity and long-term sustainability of the cropping system, by operating through the partitioning of carbon (C) and nutrients between the processes of assimilation, decomposition, immobilization and losses. In different parts of Africa, experiments and model-based studies that monitored and simulated the evolution of soil fertility in time suggest that application of organic and/or inorganic fertilizers, plus restitution of crop residues, mitigates soil organic C losses and even may increase soil C levels at varying rates depending on climate, soil and crop types and tillage method (Bationo et al., 2007; Kapkiyai et al., 1999; Titttonell et al., 2008). A cotton crop partitions an average of 45–50% of its C (Makhdom et al., 2007), and 52%, 70% and 17% of its N, P and potassium (K) towards the harvestable seeds and fibers (Rochester, 2007). The rest may return to the soil in leaf litter, lignin-rich stems and roots or be lost through burning.

In principle, if inorganic fertilizers applied to rotations of cotton with food crops would allow maintaining and building up soil fertility, they could compensate for the decrease in manure availability and the shortening of fallow periods. This is why the presence of cotton in the rotations practiced in agro-pastoral systems of West Africa is presented as a key element of their sustainability, contributing to income generation, soil fertility maintenance and food security. To examine this hypothesis, we analyzed data from a long-term crop rotation trial that was conducted in N'Tarla, southern Mali for more than 25 years under the auspice of the French overseas cooperation (Crétenet et al., 1994). More specifically, the objective of this study was to assess the role of cotton in sustaining soil fertility and crop productivity by analyzing (i) the impact of continuous cropping without fertilizers on crop productivity

in a typical rotation of cotton (*Gossypium hirsutum* L.)/sorghum (*Sorghum bicolor* (L.) Moench)/groundnut (*Arachis hypogaea* L.); (ii) the capacity of organic (manure) and inorganic fertilizers, applied separately or in combination, to maintain crop productivity in the long term under continuous cultivation; (iii) the residual effect of cotton fertilization on the yield of subsequent food crops in the rotation; and (iv) the effect that these fertilization regimes may have on soil fertility in the long term, i.e., on soil organic C and total N, available P and exchangeable K contents and pH.

2. Materials and methods

2.1. Long-term crop experiment

The experiment was set up in 1965 at the N'Tarla agricultural research station of the Institute of Rural Economics in Mali (IER—12°35'N, 5°42'W, 302 m.a.s.l.), on a field that had been left as fallow for several years. It was conducted for 25 years, until 1989. Daily rainfall, radiation, and minimum and maximum temperatures were recorded at the meteorological station of N'Tarla. Crops were strictly rainfed and grown during the rainy season, from late April to the beginning of November. Cumulative annual rainfall observed during the experiment is presented in Fig. 1. The average length of seasonal rainfall (LSR) was 161 days with rains starting from the first week of April to mid-June, and ending from the first week of October to mid-December. Average rainfall and temperature during the rainy season were 827 ± 166 mm and 28 ± 8 °C, respectively. The soil was classified as a ferric Lixisol (FAO, 2006), with a loamy-sand texture (<10% clay) at the surface, and a higher clay content in the lower horizons (30% at 60 cm depth). At the beginning of the experiment (1965), soil organic C and total N content were low, 0.38 and 0.04% respectively, and pH was 6 in the 0–40 cm soil layer; bulk density was around 1.6 kg dm^{-3} (0–40 cm).

The experiment was based on a four-year rotation, cotton/sorghum/groundnut/sorghum, from 1965 to 1975, and then, from 1976 to 1989, on a three-year rotation, cotton/sorghum/groundnut. The experiment was set up as three series of four completely randomized blocks as replications. The series were separated from each other by 2 m. In the case of the four-year rotation, sorghum was sown on two series while, depending on the year, the third series held cotton or groundnut. This particular situation (i.e., sorghum sown on two series) occurred in 1968 and every 2 years until 1974. In the case of the three-year rotation, the three series of blocks aimed at growing each crop of the rotation every year. Cultivars used during the four- and three-year rotations were: BJA 592 (1965–1977), then SM67 (1978) or B163 (1979–1989) for cotton; Tiemaring for sorghum; 56–160 (1965–1969) or 28–206 (1970–1989) for groundnut. Sowing of cotton occurred between 1st of June and 1st of July, sorghum was sown a few days after cotton, whereas groundnut was sown between 20th June and mid-July. Four treatments were studied: a control treatment (CT), a treatment receiving organic fertilizer (OF), a treatment receiving inorganic fertilizer (IF), and a treatment receiving a combination of organic and inorganic fertilizer (OIF=OF+IF). The amounts of inorganic and organic fertilizers used in the treatments were changed at some stage of the experiment, resulting in two distinct periods: the period 1 from 1965 to 1979; the period 2 from 1980 to 1989. During period 1 (15 years), fertilizers were only applied to cotton and the control treatment was not fertilized. During period 2 (10 years), fertilized treatments were changed, with also fertilizers applied to sorghum and groundnut, and CT was modified. The amounts of fertilizers applied during the experiment are fully detailed in Table 1 for the three crops of the rotation during these two periods. The total amount of manure applied during period 1 (15 t ha^{-1} on cotton)

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