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Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa

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ABSTRACT

Multiple cropping systems provide more harvest security for farmers, allow for crop intensification and furthermore influence ground cover, soil erosion, albedo, soil chemical properties, pest infestation and the carbon sequestration potential. We identify the traditional sequential cropping systems in ten sub-Saharan African countries from a survey dataset of more than 8600 households. We find that at least one sequential cropping system is traditionally used in 35% of all administrative units in the dataset, mainly including maize or groundnuts. We compare six different management scenarios and test their susceptibility as adaptation measure to climate change using the dynamic global vegetation model for managed land LPJmL. Aggregated mean crop yields in sub-Saharan Africa decrease by 6–24% due to climate change depending on the climate scenario and the management strategy. As an exception, some traditional sequential cropping systems in Kenya and South Africa gain by at least 25%. The crop yield decrease is typically weakest in sequential cropping systems and if farmers adapt the sowing date to changing climatic conditions. Crop calorific yields in single cropping systems only reach 40–55% of crop calorific yields obtained in sequential cropping systems at the end of the 21st century. The farmers' choice of adequate crops, cropping systems and sowing dates can be an important adaptation strategy to climate change and these management options should be considered in climate change impact studies on agriculture.

1. Introduction

The number of undernourished people remains highest in sub-Saharan Africa compared to other world regions and population will be more than doubled in 2050 compared to 2000 (FAO, 2006). Among effective strategies like fighting poverty, stabilizing economies and ensure access to food, increased food production in smallholder agriculture will be a key strategy for fighting hunger (FAO, 2008). Agricultural production can be increased by expanding agricultural land and by increasing the intensification of crop production through higher crop yields and higher cropping intensities. The cropping intensity in less-developed countries can be increased by about 5–10% during the next 35 years if adequate amounts of input are available (Döös and Shaw, 1999). Multiple cropping systems allow for this intensification by growing two or more crops on the same field either at the same time or after each other in a sequence (Francis, 1986b; Norman et al., 1995). They already are common farming systems in tropical agriculture today (Table 1). In multiple cropping systems the risk of complete crop failure is lower compared to single cropping systems and monocultures providing a high level of production stability (Francis, 1986a). Furthermore the second crop in a sequence may benefits from an increased amount of nitrogen derived from fixation (Bationo and Ntare, 2000; Sisworo et al., 1990) or phosphorous from deep-rooted species (Francis, 1986a) as well as from decreased disease pressure (Bennett et al., 2012) which helps to reduce the use of mineral fertilizer and pesticides. Cropping intensity is not only important in terms of agricultural production; the duration crops cover the soil will also influence albedo, ground cover, carbon sequestration potential and soil erosion (Keys and McConnell, 2005). In sub-Saharan Africa, multiple cropping systems mostly consist of cereal-legume mixed

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Table 1
Definition of terms.

Term	Definition, description
Single cropping	A cropping system with only one crop growing on the field (Bennett et al., 2012). Interchangeable with monoculture or continuous cropping.
Sequential cropping	A cropping system with two crops grown on the same field in sequence during one growing season with or without a fallow period. A specific case is double cropping with the same crop grown twice on the field.
Mixed sequential cropping	A cropping system with two intercropping systems grown on the same field in sequence during one growing season with or without a fallow period.
Growing period	The period of time from sowing to maturity determined by the sum of daily temperatures above a crop-specific temperature threshold = phenological heat unit sum (PHU).
Growing season	The period of time in which temperature and moisture conditions are suitable for crop growth, in the sub-tropical and tropical zones determined by the start and end of the main rainy season.
Multiple cropping	-“[…] may refer to either growing more than one crop on a field during the same time (intercropping), after each other in a sequence (sequential cropping) or with overlapping growing periods (relay cropping)” (Francis, 1986b; Norman et al., 1995). Examples in sub-Saharan Africa are: - groundnut–millet succession in the northern part of central Africa (de Schlippe, 1956) - wheat–chickpea succession in Ethiopia (Berrada et al., 2006) - maize double cropping in western Nigeria (Francis, 1986b) - cowpea–maize sequence cropping in the moist Savannah zone of northern Nigeria (Carsky et al., 2001) - soybean and wheat sequences in Zimbabwe (Beets, 1982) - sorghum and pigeonpea in northern Nigeria (Francis, 1986a) - sorghum double cropping in southern Guinea and Savannah zones of West Africa (Kowal and Kassam, 1978)

cropping dominated by maize, millet, sorghum and wheat (Van Duivenbooden et al., 2000). Maize- and cassava-based mixed cropping systems are common in humid East and West Africa, whereas millet-based mixed cropping is widely applied in dry East and West Africa (Francis, 1986b). Intercropping is the traditional and most frequently applied multiple cropping system in sub-Saharan Africa, however sequential cropping and mixed sequential cropping systems are also common indigenous management practices (Table 1).

Agricultural activities and consequently the livelihoods of people reliant on agriculture will be affected by changes in temperature and precipitation conditions in large parts of sub-Saharan Africa (Boko et al., 2007; Christensen et al., 2007; Müller et al., 2011). Under climate change, many areas in sub-Saharan Africa are likely to experience a decrease in the length of the growing season, while in some highland areas rainfall changes may lead to a prolongation of the growing season (Thornton et al., 2006). The degree of climate change impacts on agricultural production differs between crops (Challinor et al., 2007; Liu et al., 2008; Schlenker and Lobell, 2010; Thornton et al., 2011) and agricultural systems (Thornton et al., 2010). Therefore the farmers' choice of an adequate cropping system and crop cultivar, especially in precipitation-limited areas, might be an important adaptation strategy to changing climate conditions (O'Brien et al., 2000; Thomas et al., 2007). Lobell et al. (2008) note that the identification of practicable adaptation strategies for cropping systems should be prioritized for regions impacted by climate change. However, few studies investigate the impact of climate change on agriculture in sub-Saharan Africa considering the cropping system applied or make an effort to identify the least impacted cropping systems. The study of Thornton et al. (2009) is an exception, analysing crop yield response to climate change of a maize–bean cropping sequence in East Africa under which beans grow in a separate second growing season.

Analysing different multiple cropping systems in a climate impact study for sub-Saharan Africa requires a dataset reporting their spatial distribution in the region, which to our knowledge is not available. Some crop calendars available at the global (Portmann et al., 2010; Sacks et al., 2010) or African scale (FAO, 2010) report the growing periods of individual crops but lack reporting calendars for multiple cropping systems, while some others only cover Asian regions (Frolking et al., 2002, 2006). Fischer et al. (2002) identified potential double and triple cropping zones by comparing temperature and moisture requirements of four crop groups with climatic conditions worldwide. Thornton et al. (2006) developed a classification for agricultural systems in Africa by combining a global livestock production classification system, a farming system classification, and global land cover maps. Both datasets do not report the crop cultivars or the cropping systems.

The knowledge about the spatial distribution of multiple cropping systems needs to be expanded by more detailed information on the sub-national level. We analyse a household survey (Dinar et al., 2008) carried out in 385 districts and provinces containing more than 8600 households in ten countries of sub-Saharan Africa to fill this gap. From this survey we are able to identify the traditional rainfed sequential cropping systems with two crops grown within one year. As these are advantageous management strategies because they allow for risk spreading and increased crop productivity, we test their susceptibility to future climatic conditions in comparison to alternative management strategies by simulating crop yields with the dynamic global vegetation model for managed land LPJmL (Bondeau et al., 2007). We analyse the ability of each management strategy to maximize future crop productivity or lower negative impacts from climate change on crops. We perform this analysis in locations where sequential cropping systems are already applied by local farmers today and also for the entire region of sub-Saharan Africa in order to estimate potential benefits.

2. Materials and methods

2.1. Input data for current and future climate data

To describe current climatic conditions, we used time series of monthly temperature and precipitation as well as the number of wet days from the climate database CRU TS 3.0 (Mitchell and Jones, 2005) for the 30-year period 1971–2000 on a spatial resolution of $0.5^\circ \times 0.5^\circ$. Future climatic conditions for the 30-year period 2070–2099 were projected from the three Global Circulation Models (GCMs) MPI-ECHAM5 (Jungclaus et al., 2006), UKMO-HadCM3 (Cox et al., 1999), and NCAR-CCSM3 (Collins et al., 2006) as in the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007). As there is little consistency between GCM projections on precipitation (Boko et al., 2007) they were chosen to show a wide range of possible future precipitation patterns without being outliers (Fig. 1). NCAR-CCSM3 is among the “wet GCMs” projecting mostly increases in annual precipitation while