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The role of climate forecasts in smallholder agriculture: Lessons from participatory research in two communities in Senegal

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ABSTRACT

Climate forecasts have shown potential for improving resilience of African agriculture to climate shocks, but uncertainty remains about how farmers would use such information in crop management decisions and whether doing so would benefit them. This article presents results from participatory research with farmers from two agro-ecological zones of Senegal, West Africa. Based on simulation exercises, the introduction of seasonal and dekadal forecasts induced changes in farmers' practices in almost 75% of the cases. Responses were categorized as either implying pure intensification of cropping systems (21% of cases), non-intensified strategies (31%) or a mix of both (24%). Among non-intensified strategies, the most common forecast uses are changes in sowing date and crop variety with the latter being more prevalent where a wider repertoire of varieties existed. Mixed strategies generally used more inputs like manure or chemical fertilizers coupled with another strategy such as changing sowing date. Yield estimates suggest that forecast use led to yield gains in about one-third of the cases, with relatively few losses. Impacts varied according to the

farmers adapt to climate variability, especially helping them capitalize on anticipated favorable conditions. Realization of potential advantages appears associated with a context where there is greater varietal choice and options for intensification.

Introduction

Recent advances in climate modeling have resulted in increased ability to predict rainfall in many parts of the world with a lead time ranging from a few days to a few months, by using dynamical forecasts or statistical methods (Njau, 2010).

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Seasonal rainfall forecasts are particularly suited for rainfed farming systems, which constitute the main source of livelihood for African rural households (Klopper et al., 2006; Hammer et al., 2000; Skees et al., 1999). Empirical studies among African farmers have shown that climate forecasts can help farmers reduce their vulnerability to drought and climate extremes, while also allowing them to maximize opportunities when favorable rainfall conditions are predicted (Patt et al., 2005; Phillips et al., 2001; Roncoli et al., 2009).

This assessment of potential and opportunities has ignited scientific and institutional processes to develop and disseminate climate forecasts in Africa. In the late 1990s, a series of regional Climate Outlook Forums (COFs) was launched to produce seasonal rainfall forecasts for different parts of Africa (Hamatan et al., 2004; Patt et al., 2007; WMO and ACMAD, 1998; Aldrian et al., 2010). In West Africa, the COF known as the *Prévisions Saisonnières pour l'Afrique de l'Ouest* (PRESAO) is held each year in May, prior to the onset of the rainy season. Recent climate-related disasters, including severe droughts and destructive flooding, as well as growing evidence of climate change (Salack et al., 2011), have given new impetus to the application of climate predictive information for risk management which led the World Meteorological Organization (WMO) to establish a Global Framework for Climate Services (WMO, 2013).

Less progress has been made in assessments of the extent and impact of forecast use, particularly among vulnerable populations, such as smallholder farmers in Africa (Meza et al., 2008). Where evaluations have been conducted, they have been carried out using theoretical models (Ziervogel et al., 2005; Thornton, 2006; Hansen et al., 2009; Sultan et al., 2010; Roudier et al., 2011; Zinyengere et al., 2011) or by monitoring actual dissemination of forecasts to farmers and then evaluating how farmers use the forecasts and the impacts of any changes in management practices based on the forecast (Msangi et al., 2006; Konte, 2007; Hellmuth et al., 2007; Patt et al., 2005). Both of these approaches have limitations: (i) in the case of studies using theoretical models, results may be biased by assumptions (e.g. assuming levels of risk aversion or of trust in the forecasts among farmers); (ii) in the case of assessments based on directly observed or reported behavior, results may not be generalized due to small sample size or limited number or duration of observations. Yet, such evidence is essential to demonstrate the value of climate information to decision makers and donor agencies (Sivakumar, 2006).

In this paper, we address the questions of whether and how smallholder farmers in West Africa would use climate forecasts in making crop management decisions and whether such use would lead to benefits. We use a participatory approach, centered on farmer workshops conducted in two agro-ecological zones of Senegal, West Africa. Participatory methods, such as interactive games and role plays, have been effectively used to help farmers learn about the probabilistic nature of forecasts (Luseno et al., 2003; Patt et al., 2005; Roncoli et al., 2009), to identify potential responses and consequences of "false" forecasts (Ziervogel, 2004), to harness farmer networks for dissemination at the community level (Roncoli et al., 2011), and to illuminate the linkages between short-term tactical responses to climate variability and longer-term strategic adaptations to climate change (Bartels et al., 2012). In the case study presented here, we engaged farmers in simulation exercises that depicted their crop management strategies and exposed them to different types of climate information through multiple simulations. Climate information included recent rainfall amounts and dekadal and seasonal forecasts.

The goal of the present study is to examine how farmers would adjust their strategies to different observed and predicted climatic scenarios, including seasons of average, below average, and above average rainfall. Though we recognize that simulated choices are different from decisions made in real-life settings, experimental design tried to reproduce practices and conditions prevailing in the two sites by drawing on existing data and farmer feedback. By enabling farmers and scientists to jointly experiment with a wide range of climate and cropping scenarios, this methodology offers a cost-effective alternative to long-term empirical research, whereas the latter may not always be possible due to financial, political, institutional considerations. By comparing two sites we seek to identify factors that are associated with higher levels of and greater benefit from forecast use.

Material and methods

Study sites

The study focused on two villages in the Old Peanut Basin, a semi-arid region of southwest Senegal: Bacfassagal, near the town of Diourbel, and Paoskoto near the town of Nioro du Rip, in proximity of the Gambia border. Though the distance between villages is only about 100 km (Fig. 1), they have different climatic and socio-economic characteristics. With an average annual rainfall of about 470 mm, Bacfassagal is considerably drier than Paoskoto, with 745 mm for the years 1970–2010 (based on data from weather stations in Diourbel and Nioro du Rip). Most rainfall occurs during one rainy season, which spans from June–July to October–November. As in the rest of the Sudan–Sahel region, rainfall is characterized by high spatial and temporal variability and by periodic droughts, especially during the 1970s and 1980s (Fig. A1, in appendices). However, there is evidence of rainfall recovery in the last decade (Salack et al., 2011), a trend that was also reported by workshop participants. Nonetheless, high intra- and inter-seasonal rainfall variability, coupled with population growth and declining soil fertility, mean that local households continue to face considerable food insecurity.

Farmers distinguish two soil types, known as *joor* and *deg*. The former is an Entisol, a tropical soil with high iron content and low organic matter. The second is an Alfisol, which is more weathered and has higher clay, silt, and organic matter content. Local farming systems include a mix of compound and bush fields cultivated by rural households. Compound fields surround homesteads, are cultivated permanently, receive various amounts of amendments from rubbish heaps or livestock

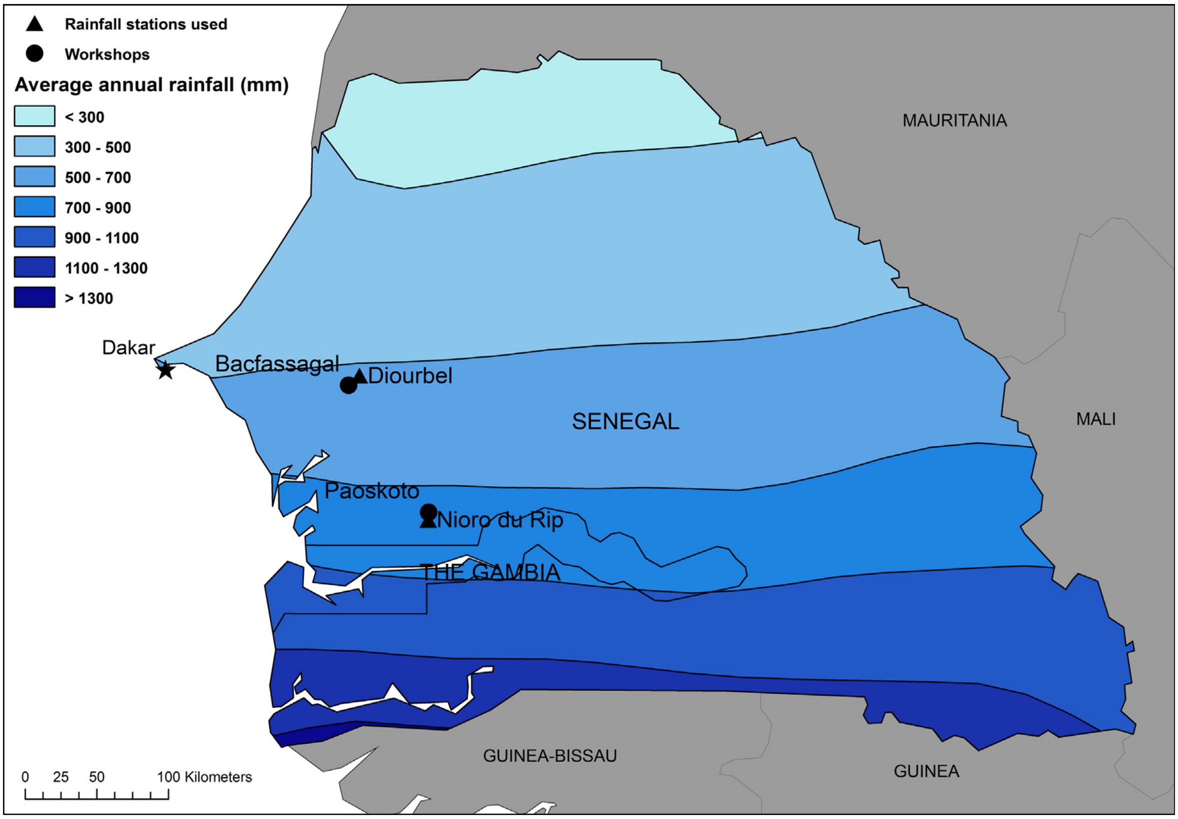

Fig. 1. Location of study sites (dots) and rainfall stations (triangles). The average cumulative rainfall is computed using CRU 3.1 data (1970/2009) (see Mitchell and Jones, 2005 for background information or http://badc.nerc.ac.uk/).

pens, and are typically planted with cereals, vegetables, and fruit trees. Bush fields are located at some distance from homesteads (ranging from 0.5 km to a few kilometers), and may be differentiated into upland or lowland fields, suitable to a variety of crops, such as millet, maize, groundnut or maize. They receive less input than the compound fields. In both communities, the main crops are millet (*Pennisetum glaucum*) and peanut (*Arachis hypogaea*). Farmers in Bacfassagal also produce sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*), which are often intercropped with millet or peanut. In Paoskoto, wetter conditions allow farmers to produce maize, especially early-maturing varieties (the most popular one is an 80-day variety known as *Early Thai*). Rainfed rice (*Oryza sativa*) is also cultivated in valley bottoms and some farmers grow water melon and pumpkin in compound plots. In both communities, farmers usually plant millet prior to the rain, applying varying amounts of organic manure and, sometimes, chemical fertilizers. Peanut and maize are generally sown after a few big rains when farmers believe that the rainy season has really started. In Paoskoto, farmers tend to use fertilizers and pesticides on peanut and maize, though they mentioned the high price of chemical inputs as a constraint.

Farmers adjust to variable climatic and agro-ecological conditions by choosing among different crops and crop varieties. Millet is planted in lighter (*joor*) soils, and maize in heavier (*deg*) ones. Peanut is preferentially cropped in intermediate soils (*joor–deg* and *deg–joor*). Five peanut varieties, with growth durations ranging from 90 to 110 days are available in Paoskoto (Clavel and N'Doye, 1997). The most common varieties are those with a longer growing duration: *73-33* (105–110 days) and *GH-119-20* (110 days), but also include drought tolerant local varieties, such as the 90-day variety *55-437,* which farmers called *Foure,* and a newly arrived, more productive variety, known as *Fleur 11*. In Bacfassagal, where drier conditions prevail, the most common peanut varieties are *Foure* (55-437) and the traditional *Foure Diaobe* – both having similar characteristics, but different types of seeds. In both villages, the most common millet variety is *Souna III*, a slightly photosensitive 85- to 90-day variety). With the recent recovery of the rains, some farmers have resumed cultivation of a long duration (120–140 days) photosensitive millet variety, known as *Sanio*, which had been abandoned during the drier past decades. This variety is more demanding in terms of water and soil nutrients, but yields more grain and biomass under conditions of adequate moisture.

Most households derive large part of their livelihood from crop production, but also engage in livestock production, trading, and other occupations. Proximity to sizeable towns and to a major road provides access to markets, inputs and other opportunities that are less available to farmers in more remote locations. Of the two communities, Paoskoto appears better endowed, not only climatically but also socioeconomically, with greater farmer access to inputs and farm equipment, even if fertilizers are also used in Bacfassagal. The village hosts a seed production cooperative, the *Cooperative des Producteurs de*

Semences d'Arachide de Paoskoto (COPROSA), started in 2007 to produce and distribute certified peanut seed. It includes about 500 farmers, who must be residents of the community, own at least 4 ha of arable land, possess sufficient labor and equipment, be free of debt, and pay an entry fee and yearly membership dues.

Climate forecast development

We use daily historical rainfall data covering the years from 1950 to 2010 from two meteorological stations near the study sites, Nioro du Rip and Diourbel. The data are provided by the *Centre d'Etude Régional pour l'Amélioration de l'Adaptation à la Sécheresse* (CERAAS), which is a regional center of the *Institut Sénégalais de Recherche Agricole* (ISRA). These data were then aggregated at the dekadal level to obtain one value for the 36 dekads of each year.

The seasonal rainfall forecasts used in this study are similar to those produced during PRESAO, the Climate Outlook Forum for West Africa. They provide a measure of relative probability that the cumulative rainfall for the upcoming rainy season may fall below, near or above the long-term normal. Values that define these terciles are based on past cumulative rainfall data (WMO and ACMAD, 1998; Patt et al., 2007). To produce probabilistic seasonal forecasts, we follow the same methodology as Batté and Déqué (2011) who use the ENSEMBLES seasonal re-forecasts (stream 2), a multi-model constituted by 45 members (5 climatic models and 9 runs). We select rainfall hindcasts initialized in May for the forthcoming rainy season, June to September rainfall, for the years between 1960 through 2005 (see Appendix A for more details).

In addition to forecasts at the seasonal timescale, we also use a forecast of rainfall for each dekad, from the European Center for Mid-term Weather Forecasts (ECMWF) mid-term deterministic rainfall forecast, archived in the Meteorological Archive and Retrieval System (MARS) of ECMWF since 1985. This dataset provides hindcasts of cumulative rainfall at a six-hour time step which have already been used successfully in a previous study focused on West Africa (Sultan et al., 2009). We first assess the accuracy of the hindcast over the period from 1985 to 2000, for different categories of dekadal rainfall, namely dry, wet, and very wet, which corresponded to respective rainfall amounts of <10 mm, 10–80 mm, and >80 mm over a 10-day period. We define these categories based on their potential agronomical impacts, respectively: not enough rain to be useful for agriculture, beneficial amount for crops, and potentially damaging rains. For each observed rainfall time series, we determined the percentiles of each threshold (10 mm and 80 mm); then we looked at the corresponding percentiles in the forecasts to select the three different categories. The forecast accuracy is given for each village by (i) the contingency table comparing observed with forecasted rainfall, (ii) the Hit Rate[1] (HR, see Appendix B for more details), and (iii) the False Alarm Rate[2] (FAR, Table A2). Globally, forecasts accuracy is better for dry dekads (HR = 0.64 and 0.73, unitless) than for wet ones. Moreover, the FAR for very wet dekads is high (0.67 and 0.77, unitless) and low for dry ones (0.44 and 0.34). Thus, when a very wet dekad is forecast for Paoskoto, the probability of 80 mm or less is 0.67. If the FAR seems very high for very wet dekads, it is important to underline that the forecasts generally do not do very big mistakes, for example, forecasting a very wet dekad for a dry one.

We then use the characteristics of the forecasts (FAR, HR) over the 1985–2000 period to generate our own random forecasts of wet and dry dekads for each year of the 1950–2010 period so that the skill score (HR and FAR) remains the same in both periods. To do so, we generate random forecasts of decadal rainfall in each village i such as:

$$X_i = Y_i + \xi \times k$$

where X_i is a random forecast at the location i, Y_i the observed decadal rainfall at the village i, ξ a white-noise parameter which represents the uncertainty of the forecast whose amplitude is defined by a scale factor k. 10,000 random factors are generated by varying the value of k. A value of 0 for k indicates a perfect forecast and the skill score decreases with an increase of k. We then evaluate the performance of these random forecasts X_i by computing HR and FAR for each category of decadal forecasts over the 1950–2010 period. Finally we retained the forecast X_i whose HR and FAR for each category are the closest to HR and FAR of ECMWF forecasts over the 1985–2000 period.

We therefore forego the deterministic aspect of the ECMWF forecast to retain only the typical error and success rate in predicting a forthcoming dekad of such a state-of-the-art forecast system.

Participatory workshops

Workshops were designed based on a Companion Modeling approach (http://www.commod.org/), which aims to explore the integration of local and scientific knowledge systems (D'Aquino et al., 2003). In each community, a two-day participatory workshop was held in May 2011 to examine whether and how farmers might use seasonal and 10-day forecasts (Barreteau, 2003; Ziervogel, 2004; Patt et al., 2005; Roncoli et al., 2009). A research team visited the selected villages one month prior to the workshops to introduce the project, to work on arrangements with local organizations (CERAAS and COPROSA), and to collect information that would guide the design of workshop exercises.

Because we wanted to study different potential reactions to forecasts and because we wanted to be able to speak with everyone about the forecasts, 16 farmers were recruited in each community. Not all participants were able to complete

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[1] Probability that an observed event is forecast.

[2] Probability that a forecast event does not occur.

the entire set of exercises in the prescribed way, resulting in usable data set from 13 participants in Bacfassagal and 12 in Paoskoto. Indeed, some of them left the workshop for a while (it was two days long), were replaced by other farmers during the workshop, or turned in results that were incomplete or not amenable to analysis (e.g. no sowing or no harvest in a particular year). Guidelines for workshop planning sought to ensure that all social groups in the community were represented, including participants of different ages, genders, educational levels, and landholding size. However, operationalizing this ideal proved challenging in view of local social norms and hierarchies, as also happened in other similar projects (Roncoli et al., 2009; Ziervogel, 2004). Despite efforts, it proved impossible to recruit and retain women for the entire duration of the workshops. A few women attended unofficially; although they did not complete the workshop exercises and therefore they could not be included in the analysis. Most official participants owned some livestock, used chemical inputs, and had access to radios and cell phones; all were men. On average, Bacfassagal participants were older, had more household labor, and owned more livestock than Paoskoto participants. In contrast, Paoskoto participants had higher education levels and larger landholdings than participants from Bacfassagal. The larger landholdings in Paoskoto are probably because most participants were members of the seed cooperative and as such had to plant at least 2 ha for seed production (Table 1). In sum, while participants were broadly representative of viable farming households, they did not include the most vulnerable or marginal social groups, an issue that limits the generalizability of results.

The workshop protocol utilized two consecutive rounds of a simulation exercise during which participants simulated crop management decisions based on a set of the past three years in each location (Table A3).

During the first round, a sheet of paper was provided to each participant, who detailed his crop management strategies over a whole rainy season, which was segmented into 10 day units (dekads). On each sheet, a number of rows symbolized different fields. Three columns on the left side of the sheet contained information characterizing each field, namely whether compound or bush field, prevailing soil type using farmer defined categories, and main crop and crop variety grown (see Fig. 2). It was assumed that each field had only one crop and one variety of that crop. A top row represented the sequence of dekads, spanning from the last dekad of May to the first one of November. At the end of each dekad, farmers were then given information about the total rainfall obtained during that dekad. On this sheet, workshop participants represented their crop management tasks (sowing, applications of organic manure, chemical fertilizers, and pesticides, weeding and harvesting) for each dekad and each field. Using different colors, which they helped to select at the start of the workshop, farmers drew colored circles representing each task and a black cross for “no action”. At the extreme right of the sheet a last column elicited participants’ assessment on a scale of 1 (very bad yield) to 5 (very good yield) of what the crop yield might be in light of the conditions and practices entered (Fig. 2). This initial phase was repeated for years 1977, 1979, 1992 in Paoskoto and years 1960, 1966, and 1985 in Bacfassagal, and was used as a baseline, to represent what farmers do normally, based on rainfall received but without access to forecast information. This process was repeated again for each of the past years considered.

The second round repeated the same process for the same rainfall years, without telling participants that they consisted of the same years, to see whether they would modify their strategies. This time farmers were also provided with climate forecasts, including a seasonal rainfall before the first dekad of the year and 10-day rainfall forecasts at the start of each dekad. For each year we computed the probability of the seasonal rainfall having a wet, normal, or dry tendency (referring respectively to the total seasonal rainfall being above, near, or below normal). The forecast was synthesized into a brief statement such as: “the rainy season is expected to be rather wet” or “is expected to be not too wet and not too dry” in order to simplify the conventional method using tercile probabilities (see e.g. Manatsa et al. (2012) for a new approach). The statement for each forecast was translated from French into Wolof for Paoskoto and into Serer for Bacfassagal. In addition to seasonal forecasts, each 10 days, participants were provided with a forecast of cumulative rainfall for the upcoming dekad, expressed in terms of three categories: dry, wet or very wet. To reflect the inaccuracy of such forecasts, neither seasonal nor dekadal forecasts were formulated to be perfectly accurate: for example, the seasonal rainfall forecast for the 1985 rainy season predicted a dry tendency, while the actual rainfall was near “normal” (Table A3).

At the end of each sequence, that is, at the end of the rainy season, participants were asked to qualitatively estimate what they thought their yields would be given the practices they chose and the rainfall they received. This activity proved more challenging than expected, not always translating into consistent results. In some cases farmers’ claims that forecast use led to increased peanut yields were contradicted by their marks on the worksheet. In other cases, farmers did not change practices, but estimated their yields differently between the two rounds. Farmers’ yields assessments were, therefore, replaced by the appraisal of an agronomist from CERAAS/CIRAD (Centre International en Recherche Agronomique pour le Développement) who has been working in the area for several years. For each field, each farmer and in each year, the agronomist com-

Table 1
Some parameters describing both panels (16 people in each panel).

Parameters	Bacfassagal	Paoskoto
Average age of participants (standard deviation)	48.9 (13)	42.3 (12)
Number of participants who went to primary or koranic school	5	8
Average number of able-bodied workers per household (at least 12 years old)	9.7	7.6
Average cultivated area (ha) per household	5.1	8.7
Average number of animals (donkey, goat, sheep, cattle, horse) per household	12.5	11.2

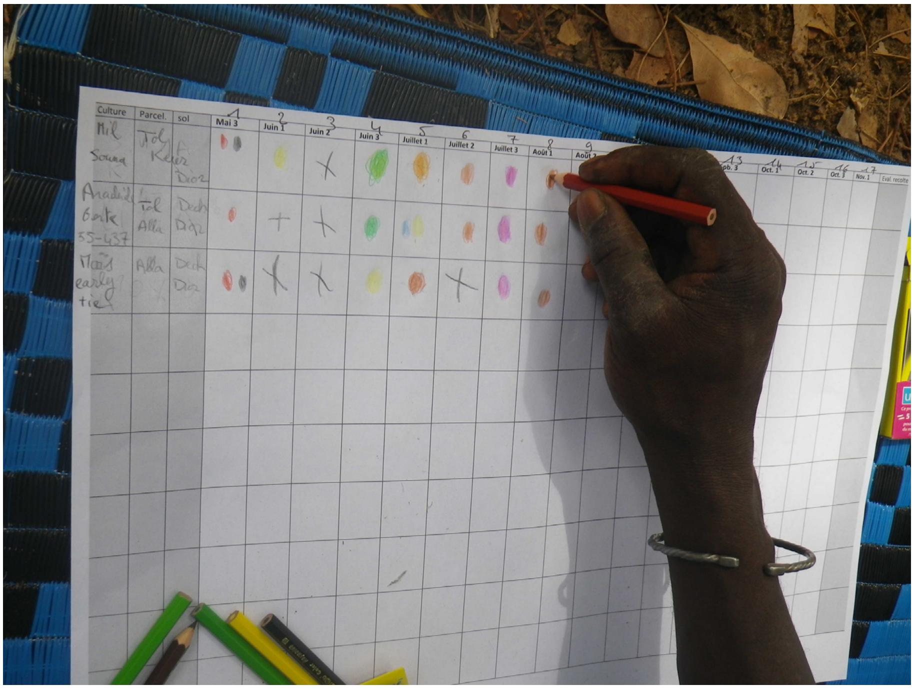


Fig. 2. Exercise sheet used during the workshops (Paoskoto).

pared the cropping activities by pairs (with and without forecast). He focused on changes of: crop cultivar, sowing date, harvest date, and use of fertilizers/manure and timing. He then compared these changes with the observed rainfall data to decide if they would have a positive, negative or null effect on yield. His assessment is therefore only relative. We detail in Table A4 the main changes reported by the experts for each category of impact (positive, null, negative) and in Table A5 three concrete examples of how he proceeded. This produced a database of 177 cases, with a case being defined as the comparison of round #1 and round #2 for a particular farmer, field, and year. While this approach has obvious limitations, it nonetheless provided an estimate of potential impact of forecast use relative to a wide range of cropping practices and rainfall conditions.

At the end of the workshop, participants were engaged in a general discussion aimed to elicit information on traditional forecasting knowledge as well as feedback on the scientific forecasts and workshop process. In addition, questionnaires were used to collect background data on each participant as well as information on habitual crop management practices, to be used in triangulating each participant's entries on the exercise sheet. Farmers' discussion of traditional knowledge focused on predictions at a timescale shorter than the season, namely indicators announcing that the onset of the rainy season was near or the occurrence of a rain event within days. These included temperature fluctuations, germination of new leaves on baobab and tamarind trees, singing by certain birds, appearance of specific constellations, as well as divinations by spiritualists (Roudier, 2012). Many participants expressed confidence in these forecasts, whether based on environmental observations or spiritual practices, even while admitting that it is not infallible. However, a notable proportion (27%) of participants had no knowledge of or paid no attention to such forecasts.

At the same time, farmers expressed interest in scientific climate information. In Bacfassagal, they discussed potential applications of dekadal forecasts to timing of planting, weeding, and harvesting, while they found seasonal rainfall forecasts be less actionable, given their limited options and resources (Roudier, 2012). In Paoskoto seasonal forecasts were better received and deemed to be useful for guiding choice of crops and varieties. For example, some workshop participants asserted that a forecast for heavy seasonal rainfall would prompt them to sow more maize and rice.

Workshop results

Changes in crop management strategies in response to forecasts

The simulation exercises illustrated the potential role that predictive climate information, including seasonal and dekadal rainfall forecasts, can play in shaping farmers' crop management strategies in situations of climate uncertainty. However, the distinct effect of each type of forecast or piece of information may be difficult to ascertain: field studies conducted among African smallholders indicate that farmers combine information from different sources and multiple timeframes (Orlove et al., 2010, Roncoli and Ingram, 2003; Roncoli et al., 2002). Farmers may enter the season with some expectation based on prior experience, empirical observations, and traditional knowledge, and then adjust strategies as shorter-term forecasts and real-time information become available (Orlove et al., 2010, Furman et al., 2011). Thus, most of the results reported below pertain to responses to the dekadal forecasts. While specific responses to seasonal forecasts were reported less frequently, it must be noted that such forecasts also constituted the informational context in which shorter term adaptations were enacted.

Table 2 shows changes in management strategies that were implemented by participants between round #1 (before receiving forecasts) and round #2 (after receiving forecasts). In 43 of 177 cases, there was no change between the two rounds. The proportion of non-response was greater in Paoskoto than in Bacfassagal but this difference does not pass a Fisher significance test ($\alpha = 5\%$). Though it may be easy to interpret this finding as indicating that the forecast was not useful in 25% of cases, this may also point to a more complex role that information plays in decision making. For example, since some of the forecasts presented to workshop participants predicted a normal rainy season, they may not have induced participants to change their decisions. Furthermore, evidence from field studies (Roncoli et al., 2009) indicates that climate forecasts may intervene in the decision process – not by modifying decisions – but by reinforcing what a farmer has already decided based on his/her own experience and observations. Thus, the information may also have an important psychosocial effect by providing farmers with reassurance and encouragement to stay the course and work hard in the hope of a good harvest (Roncoli et al., 2009).

When farmers did change their practices, these responses can be classified into three categories: (i) options that do not entail any intensification: these include stopping using inputs or changes in the agriculture calendar – particularly planting time – and changes in the choice of crops and/or varieties; (ii) options that imply increased intensification, such as enriching soils with mineral or organic fertilizer and (iii) options using a mix of intensified and non-intensified practices.

Among forecast uses, adjusting sowing date in response to 10-day rainfall forecasts was the most common response in both villages. Table 3 illustrates how farmers from the two villages decided to sow earlier or later than originally planned after receiving the 10-day rainfall forecast. This information is particularly important at this time, which is marked by high uncertainty and anxiety for local farmers. Typically, farmers strive to sow as early as possible after the first big rain event of the season in order to avoid the risk of crops not reaching maturation if the rainy season ends prematurely. This strategy, however, exposes the newly planted crops to the risk of a dry spell that may occur early in the season (Marteau et al., 2011). Failure of germination leads to loss of seeds as well as greater labor demands as farmers must replant their fields. Delayed sowing entails other disadvantages and potential risks: it causes crops to miss the nitrogen that becomes available through mineralization following the first rains, which is especially important when no fertilizer is applied (Birch, 1958; Sparling and Ross, 1988; Badiane, 1993). Delayed sowing also exposes crops to greater weed pressure, because weeds begin growing earlier than the crop, so that the crop has less capacity to compete with the weeds, as well as to the risks associated with a shortened growing season (Andrews, 1973; Stoop et al., 1981; Vaksmann et al., 1996). These risks notwithstanding, during the simulation exercises, farmers postponed sowing of peanut or maize if a dry spell was predicted for the ensuing dekad. Because heavy rains might damage young plants and slow growth through reduced solar radiation, farmers also postponed sowing if heavy rains were predicted for the ensuing dekad.

Another notable change between the two rounds pertains to the proportion of various crops and varieties in farmers' cropping decisions, as also found in other studies (Tarhule and Lamb, 2003; Ziervogel et al., 2005; Roncoli et al., 2009). In the course of workshop simulations, changes in cultivar were more common than changes in crop type, which were marginal

Table 2
Number of observed changes between round #1 and round #2. "Only" means that it is the only type of change used. "+" means that the strategies are used together.

Category of action	Changes	Bacfassagal	Paoskoto	Total
No action	Null	17	26	43
Non intensified	Cultivar + sowing	0	6	6
	Cultivar + less inputs	0	1	1
	Only cultivar	0	7	7
	Sowing + less inputs	0	4	4
	Only sowing	14	12	26
	Only harvest	3	0	3
	Only Less inputs	5	3	8
	Total	22	33	55
Intensified	Only manure	2	4	6
	Only NPK	9	22	31
	Total	11	26	37
Mixed (intensified & non-intensified)	Cultivar + NPK	0	2	2
	Sowing + NPK + cultivar	0	3	3
	Sowing + NPK + harvest	4	0	4
	Sowing + NPK	11	9	20
	Sowing + manure + NPK	0	2	2
	Sowing + manure	2	4	6
	NPK + harvest	3	0	3
	Manure + harvest	2	0	2
	Total	22	20	42

Table 3
Description of changes in main sowing date due to forecasts (observations during workshops).

Crop	Timing	Configuration rainfall/forecast	Response	Example
Millet	Late May/early June	Wet dekad forecast after a dry dekad	Earlier sowing, to benefit from rain	Paoskoto, 1979
Maize	From early June to late July	Dry dekad forecast after a rainy dekad	Delayed sowing, to avoid drought	Paoskoto, 1977
Maize	Early June	Very wet dekad forecast after a rainy dekad	Delayed sowing, to avoid crop destruction	Paoskoto, 1979
Peanut	From early June to late July	Dry dekad forecast after rainy dekad	Delayed sowing, to avoid drought	Bacfassagal, 1985

in both villages. This was particularly the case where a wide repertoire of options was available to farmers, such as in Paoskoto where farmers have access to at least five peanut varieties. According to the agronomic literature (Clavel and N'Doye, 1997) as well as farmers' own knowledge, these varieties may be classified in two categories: wet year varieties (28-206 and GH 119-20) and dry year varieties (73-33, *Fleur 11, Fouré, and Fouré Diaobé*,). Fig. 3 shows that without climate forecasts (round #1), farmers favor dry year varieties, which account for 80% of the peanut sowed each year, reflecting a strong risk aversion. With climate forecasts (round #2), on the other hand, farmers altered the relative proportion of different types of varieties, except in one case, that of a forecast for high uncertainty. Typically the proportion of wet year varieties was increased if the season was predicted to be wet, as for 1979 in Paoskoto. These responses, however, were limited to Paoskoto where "wet year varieties" were among available options, whereas Bacfassagal farmers were limited to only two options, both "dry year varieties" (*Fouré and Fouré Diaobé*). No such shift of variety in response to forecasted seasonal rainfall was noted for other crops, such as millet.

Other changes in response to the 10-day forecasts were recorded among workshop participants. For instance, farmers increased weeding in response to predictions for heavy rains, which would make it difficult to access fields in the aftermath. This response was intended to control weed proliferation as well as to facilitate infiltration and, therefore, limit runoff and soil erosion (Lamachere, 1991). Farmers also decided to harvest earlier than planned in anticipation of a rainy dekad, to prevent peanut from germinating in the soil or to avoid damage to peanut and maize by pests and diseases that thrive in humid conditions (Table 4). Responses to dekadal forecasts were also shaped by contextual factors, such as whether the dekad in question fell early or late in the rainy season and whether the preceding dekad had been dry. These factors were taken into account as farmers sought to estimate the probability and potential impact of anticipated dry spells or heavy rains.

While simulation games do not reflect the complexity of crop management strategies in a real-life context, these results are important in that they clearly indicate that climate forecasts can affect agricultural decision-making. However, the most critical question is whether forecast-induced changes in crop management strategies translate into tangible benefits for farmers.

Impacts of forecast use in crop management strategies

Results show that there is a great deal of variation in terms of gains and losses that farmers may face as outcomes of decisions made in response to forecasts (Fig. 4a). In 93 of the 177 cases there is no difference between the two rounds, suggesting

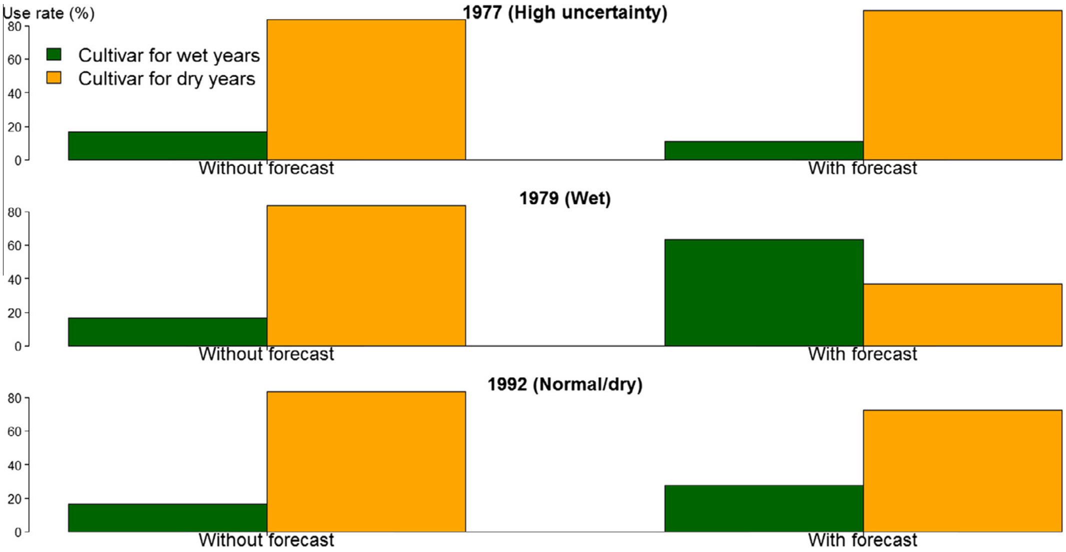


Fig. 3. Peanut cultivar utilization rate, for each year, in Paoskoto. Cultivar for wet years are *28-206* and *GH 119-20*, cultivar for dry years are *Fleur 11*, *55-437* and *73-33*. The seasonal forecast of each year is given in brackets.

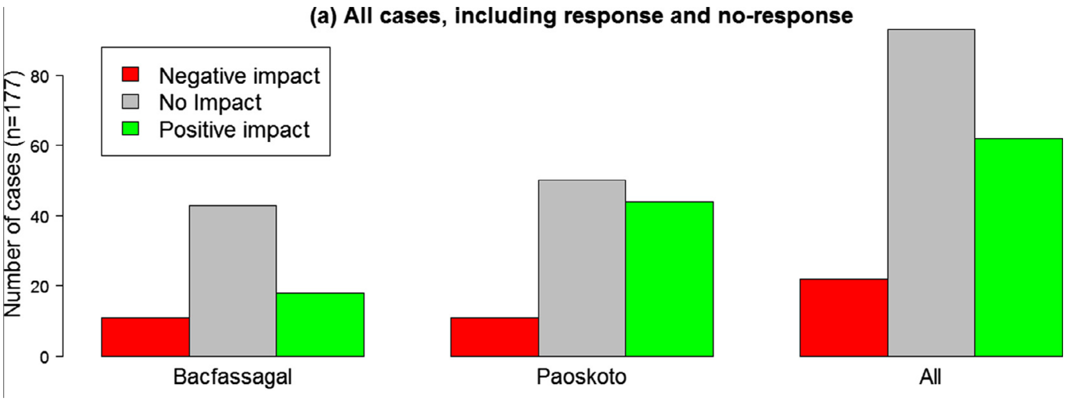
Table 4
Description of changes in main harvest date due to forecasts (observations during workshops).

Configuration rainfall/forecast	Response	Explanation	Example
Rainy dekad (>80 mm) forecasted at the end of the rainy season	Earlier harvest if crop maturation is complete	To avoid damage to grains due to moisture	Bacfassagal 1966
Rainy dekad (>80 mm) forecasted at the end of the rainy season	Delayed harvest if crop maturation is not complete	To benefit from residual moisture	Paoskoto 1979

that introducing climate forecasts may not have a significant effect on crop yields. Nonetheless, there is evidence that forecast use is associated with gains in crop yields in 62 of the 177 cases and with losses in only 22 cases. When disaggregated by village, yield gains were registered more frequently in Paoskoto (44 of 105 cases) than in Bacfassagal (18 of 72 cases). These differences between villages in forecast impacts are however only significant at the 10% confidence interval using a Fisher test ($p = 0.06$).

When removing cases of “no-response” from the analysis, the remaining cases ($n = 134$) show that forecast use is likely to be advantageous (Fig. 4b). In fact, positive impacts are recorded in 62 of 134 cases and dominate cases of null effect (50/134). Significant differences are to be noted between responses in Bacfassagal and Paoskoto (Fig. 4b). The null effect still prevails in Bacfassagal, despite the fact that all participants changed strategy between round #1 and round #2. In this village, forecast application appears to be potentially risky given that negative and positive impacts occur with almost the same frequency. Even if potential for negative outcome seems to be low, for strongly risk-averse farmers, this rate might still be too high, as there is almost no safety net such as insurance to prevent from a bad harvest. On the other hand, forecast use appears to be potentially beneficial in Paoskoto, where changes in crop management decisions prompted by forecasts led to yield gains in 44 of the 79 cases, and to yield losses in only 11 of the 79 cases.

Impacts of forecast use appear to differ according to the type of response strategy (Fig. 5). These strategies include 55 instances that do not imply intensification (changes farming calendar, choice of crops and varieties) as well as 37 instances of intensification by means of organic or inorganic inputs and 42 instances using a mix of intensified and non-intensified strategies, e.g. choice of crops and organic inputs (Table 2). Forecast use appears to confer benefits most when associated



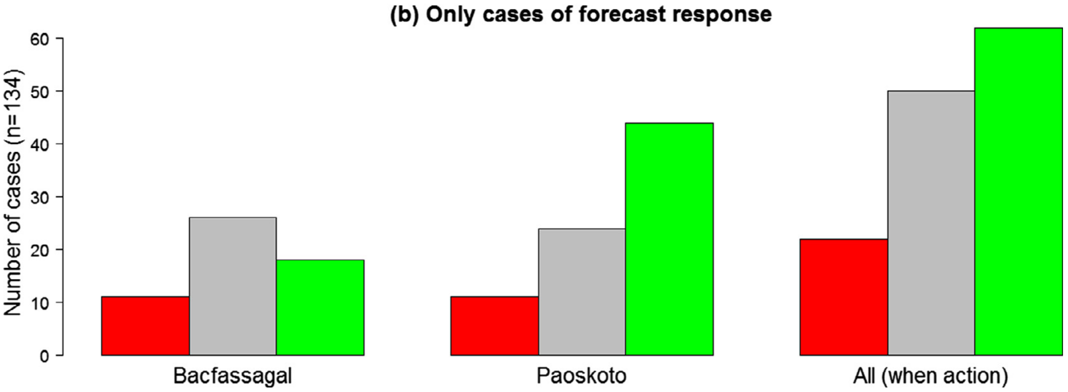


Fig. 4. Impacts of the crop management changes on yields between round #1 (no forecast) and round #2 (forecast available) when (a) considering all 177 cases and (b) only cases with an action in response to the forecasts (i.e. we removed all the situations where the management options are exactly the same between both rounds). A case is defined by a village, a year, a farmer and a field.

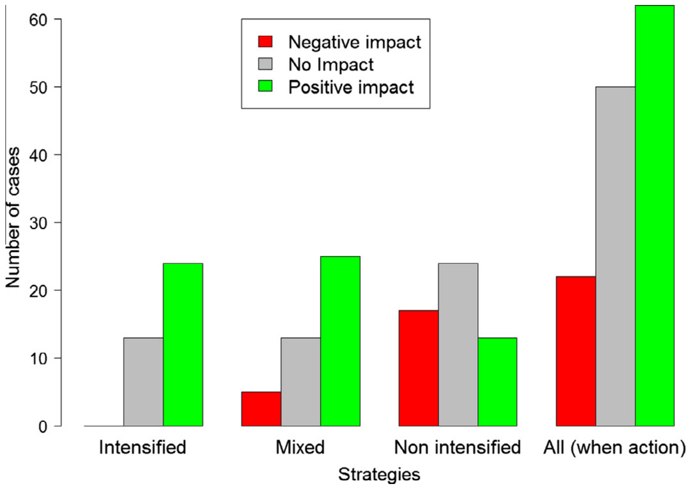


Figure 5. Focus on the cases where farmers changed their management strategies in response to forecasts, and their impact on yields. Strategies are divided in three categories, namely Intensified (left panel), non-intensified (middle right) and mixed (at least one intensified strategy with one non-intensified). A case is defined by a village, a year, a farmer and a field.

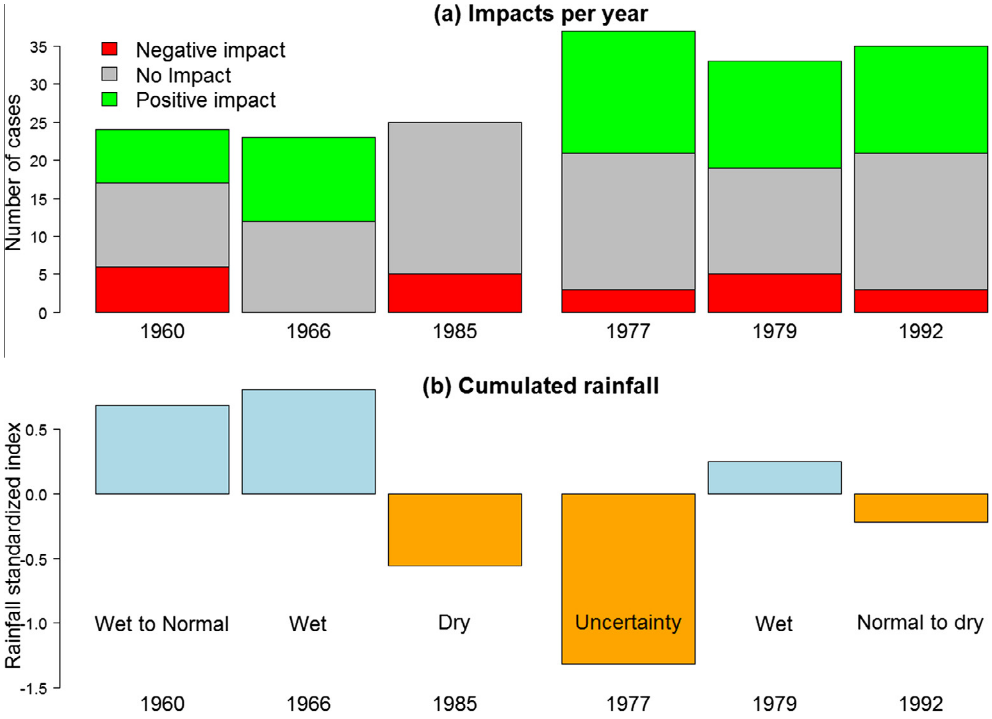


Figure 6. (a) Impacts of the crop management changes on yields between round #1 (no forecast) and round #2 (forecast available), for each year. A case is defined by a village, a year, a farmer and a field (177 different cases here). (b) Standardized anomalies of annual rainfall for each considered year (baseline: 1950–2010) in the two villages. Standardized index for year y is: $(x(y) - \text{mean}(x))/\text{sdv}(x)$. We added on panel (b) the forecast for each year (e.g. "wet to normal").

with intensification (24/37 cases) and mixed strategies (25/42 cases). For options without intensification the impacts are less clear, with prevalence of null effects and near equivalence of negative and positive effects.

The nature of the predicted rainy season together with the skills of both seasonal and dekadal forecasts seem to be factors shaping forecast effects. Fig. 6a shows the variation across the different years considered in the simulation exercises (1960, 1966, and 1985 in Bacfassagal and 1977, 1979, and 1992 in Paoskoto). In Bacfassagal, no negative impacts were estimated for 1966, which was the wettest among all years used in the simulation, during which both seasonal and dekadal forecast

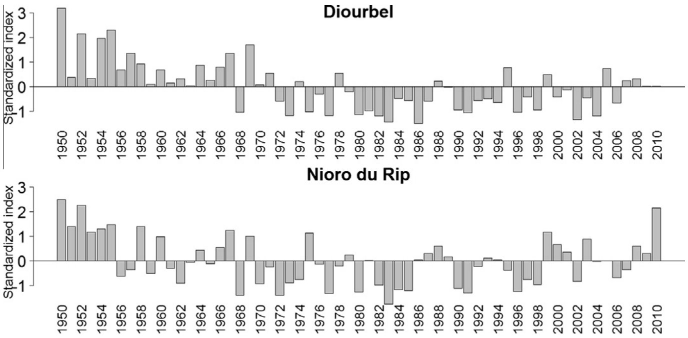


Figure A1. Standardized index of annual cumulate rainfall (for years 1950–2010) for Diourbel (top) and Nioro du Rip (bottom).

performed well (Fig. 6b). On the contrary, no positive impacts were registered in 1985, which was a dry year, with a very low skill for the dekadal forecast (only 1 of the first 6 dekads was correctly predicted). The inaccurate forecasts for those early dekads led farmers to postpone sowing dates to mid-July, to avoid predicted dry spells. This meant that crops only reached filling and maturation stages in mid-September, when rains are less frequent, exposing crops to water deficits that resulted in yield reduction. Year 1977 is also of interest, as the impacts are rather positive although this is a dry year with an uncertain forecast. As detailed in Table 3, farmers used an accurate dekadal forecast predicting a dry spell to postpone sowing.

In sum, there is suggestive evidence that African farmers are able to use climate forecasts in order to maximize benefits from anticipated favorable conditions. These potential advantages seem to be associated with the availability of varietal choices and with opportunities to intensify cropping systems. On the other hand, the combination of dry years and inaccurate forecasts seem to lead to negative yield impacts, suggesting the need for caution to be exercised at times when farmers are most vulnerable.

Discussion and conclusion

Growing concerns about vulnerability of African rural households to climate variability and change have fueled investments in the development of climate services to enhance farmers' adaptive capacity. Simulation exercises conducted in two agro-ecological zones of Senegal provided examples of how farmers could use predictive climate information at different timescales (seasonal and dekadal rainfall forecasts). In 75% of the cases, farmers identified at least one strategy they could use in response to forecasts. Most adaptations pertained to dekadal rather than seasonal forecasts, though the latter were also used, especially where farmers had a wider range of management options. Potential responses included strategies that do not entail intensification (e.g. changing sowing date or crop variety), practices that lead to greater intensification (applying manure or chemical fertilizers) and mixes of the two. Strategies without intensification and mixed practices were far more common than those with only intensification.

The overall effect of these adaptations on estimated yields was relatively limited, especially in Bacfassagal. However, as it is the case with response rate, estimated impacts varied considerably depending on several factors, including the community context, response strategy, forecast type and accuracy and amount and distribution of rainfall to date. Yield gains were estimated more commonly in the wetter site. Furthermore, at the farmer level, estimated gains were higher for responses that entail intensification and mixed strategies, even though practices without intensification were more prevalent. Finally, negative impacts of responses to forecasts occurred mostly in dry years with wrong forecasts and among farmers from the drier site.

While these results are indicative of how African farmers may use and benefit from predictive climate information, they must be interpreted with caution due to several limitations. First, because of the non-random and small-scale nature of the sample size, which included no women, findings can hardly be generalized to the broader population. Second, decisions made in an experimental setting only approximate those made in everyday life. Third, for the sake of experimental simplicity, we did not consider whether or how scientific forecasts interact with those based on traditional knowledge. Discussions with workshop participants indicated that farmers hold, trust, and use traditional knowledge, even though they are also open to receiving scientific information. Fourth, the workshop protocol did not address the problem of access to forecast information, which is a major barrier to utilization.

Future iterations of the workshop protocol may incorporate additional exercises to address these issues. In addition, the methodology can be refined based on lessons learned during implementation. For example: (a) organizers need to negotiate with village leadership to ensure participation by women and other disadvantaged groups; (b) the workshop agenda must allow at least half a day for instructions and for participants to become comfortable with the exercises; (c) the number of simulations must be restricted to 3 or 4 seasons to prevent participants from becoming bored or hasty; (d) basic colors should be used to avoid the need for multiple hues of the same color; and (e) adequate attention must be given to local language translation of key terminologies and of the statement summarizing the seasonal forecast.

Despite limitations, both findings and methods presented here offer key insights for the production of actionable climate information. They validate previous research among African rural communities that has shown that forecasts must be appropriately targeted to focus on where they have the best comparative advantage; they must be packaged in ways that include different kinds of information, across scales and sectors; and they are most useful and effective when introduced in a context that provides farmers with a range of response options. The high diversity and complexity of farmers' responses also emphasizes the importance of such participatory, experiential, and iterative experiments. Such interactions enable us to better understand about the large range of conditions they operate in; the opportunities and constraints they face; the potential impact of predictive climate information on their yields; and the additional supports that may help them translate climate forecasts into adaptive practices.

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Appendix A

These data come from the ECMWF (European Centre for Medium-Range Weather Forecasts) and are available for each model at a $2.5^\circ \times 2.5^\circ$ spatial resolution. We have then translated each year these hindcasts into a probability of having a rather "dry", "normal" or "wet" rainy season.

These three categories were created using the Global Precipitation Climatology Centre (GPCC) Full Data Reanalysis version 4 dataset, which provide monthly rainfall data for years 1901–2007 for the entire world. We were thus able to compute for Senegal the threshold quantiles of the cumulative rainfall distribution for years 1960–2005. The predicted probability is the fraction of individual forecast outputs (out of m months by n ensemble members) which yields precipitation amounts above (or below) the corresponding threshold. A quantile-quantile calibration technique was used to correct each forecast data.

Appendix B

Computing Hit Rate (HR) and False Alarm Rate (FAR) is a means of testing the skill of categorical forecasts (Mason and Graham, 1999; WMO, 2006). We computed a contingency table based on the three rainfall categories and calculate the HR and FAR. Table A1 and both equations give an example of how to compute HR and FAR for the wet dekad.

$$\mathrm{HR} = \frac{\sum \mathrm{hits}}{\sum \mathrm{hits} + \sum \mathrm{misses}}$$

Table A1

Example of how to use a contingency table to compute the HR and FAR. "Hits" is the number of wet dekads that have been accurately forecast. "False alarms" is the number of normal or dry dekads that have been forecast as wet dekads. "Misses" represent the number of wet dekads that have been forecast as normal or dry dekads.

Observed rainfall	Predicted rainfall		
	Dry dekad	Normal dekad	Wet dekad
Dry dekad	Correct reject	Correct reject	False Alarms
Normal dekad	Correct reject	Correct reject	False Alarms
Wet dekad	Misses	Misses	Hits

Table A2

Accuracy of 10-day forecasts using the Hit Rate (probability that an observed event is forecast, notation HR) and the False Alarm Rate (probability that a forecast event does not occur, notation FAR), for each village and each rainfall category, for years 1985/2000. All rates are unitless.

	Category of forecast	HR for years 1985/2000	FAR for years 1985/2000
Paoskoto	<10 mm	0.64	0.44
	[10:80 mm]	0.47	0.48
	>80 mm	0.33	0.67
Bacfassagal	<10 mm	0.73	0.35
	[10:80 mm]	0.44	0.52
	>80 mm	0.20	0.77

Table A3
Selected years in Bacfassagal and Paoskoto. Forecasts and observations are relative to 1960–2010.

Village	Year	Probabilities (W/N/D)	Seasonal forecast	Observation (tercile)
Bacfassagal	1960	0.36/0.35/0.29	Wet to normal season	Normal
	1966	0.49/0.27/0.23	Wet season	Wet
	1985	0.18/0.32/0.5	Dry season	Normal
Paoskoto	1977	0.33/0.35/0.32	High uncertainty, maybe normal	Dry
	1979	0.39/0.32/0.29	Wet season	Wet
	1992	0.28/0.37/0.36	Normal to dry season	Normal

Table A4
Description of the crop management changes between both rounds leading to positive, null or negative impacts on yields (according to the expert).

Positive impact	Null impact	Negative impact
– Adding inputs in a rather wet season; timing of such a practice – Adequate variety according to the rainy season – Successful shift in the sowing date – Harvest before a heavy rain – Better timing of fertilizer application – Better timing of manure application	– No change in management – Dry sowing instead of sowing with the first rain – Use inputs during a rather dry period	– Inadequate variety according to the rainy season – Unsuccessful shift of the sowing date (dry spell during early stages, drought during grain filling stage, excess of water after maturation) – No use of inputs while it would have been relevant (they decided not to use inputs anymore)

Table A5
Three specific cases of the expert assessment. Each row is a comparison of cropping practices between both rounds for a given location, farmer and field. The comments are the one given by the expert.

Location/ year	Seas. forecast	Change	Comment	Expert assessment
Paokoto/ 1979	Wet	Groundnut cultivar (changes from F11 to 28-206)	Positive effect because the 28-206 cultivar is expected to yield more this year. Indeed, the F11 cultivar does not have the dormancy characteristic, so the young seeds would have immediately germinated. Thus the F11 maturity stage would have occurred during a rainy period which would have led to bad yield.	POSITIVE
Bacfassagal/ 1985	Dry	Delayed sowing date (03/06 to 03/07, groundnut)	Negative effect because the rainy season is quite short with not enough water at the end of the season	NEGATIVE
Paoskoto/ 1977	Uncertain	Add fertilizers in round #2 (Maize)	No effect because the sowing is quite early (June 2nd) and followed by a dry period. So fertilizers won't have a positive effect	NULL

$$\mathrm{FAR} = \frac{\sum \text{ false alarms}}{\sum \text{ Correct rejections} + \sum \text{ false alarms}}$$

References

Aldrian, E., Oludhe, C., Garanganga, B.J., Pahalad, J., Rojas Corradi, M., Boulahya, M.S., Dubus, L., Ebinger, J., Fischer, M., 2010. Regional climate information for risk management. Procedia Environ. Sci. 1, 369–383.

Andrews, D.J., 1973. Effects of date of sowing on photosensitive Nigerian sorghums. Exp. Agric. 9, 337–346.

Badiane, A.N., 1993. Le statut organique d'un sol sableux de la zone Centre-Nord du Sénégal (Ph.D. thesis). Université de Nancy, INPL-ENSAIA, France, p. 200.

Barreteau, O., 2003. Our companion modelling approach. J. Artif. Soc. Soc. Simul. 6 (1).

Bartels, W., Furman, C., Diehl, D., Royce, F., Dourte, D., Oritz, B., Ziierden, D., Irani, T., Fraisse, C., James, J.W., 2012. Warming up to climate change a participatory approach to engaging with agricultural stakeholders in the Southeast US. Reg. Environ. Change 12.

Batté, L., Déqué, M., 2011. Seasonal predictions of precipitation over Africa using coupled ocean-atmosphere general circulation models: skill of the ENSEMBLES project multi-model ensemble forecasts. Tellus A 63, 283–299.

Birch, H.F., 1958. The effect of soil drying on humus decomposition and nitrogen availability. Plant Soil 10 (1958), 1–31.

Clavel, D., N'Doye, O., 1997. La carte variétale de l'arachide au Sénégal. Agric. Dév. 14, 41–46.

D'Aquino, P., Le Page, C., Bousquet, F., et Bah, A., 2003. Using self-designed role-playing games and a multi-agent system to empower a local decision-making process for land use management: the selfcormas experiment in Senegal. J. Artif. Societies Soc. Simul. 6.

Furman, C., Roncoli, C., Crane, T., Hoogenboom, G., 2011. Beyond the 'Fit': introducing climate forecasts among organic farmers in Georgia (U.S.). Climatic Change 109 (3–4), 791–799.

Hamatan, M., Mahe, G., Servat, É., Paturel, J.-E., Amani, A., 2004. Synthèse et évaluation des prévisions saisonnières en Afrique de l'Ouest. Sécheresse 15, 279–286.

Hammer, G., 2000. A general systems approach to applying seasonal climate forecasts. In: Hammer, G., Nicholls, N., Mitchell, C. (Eds.), Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems: The Australian Experience. Kluwer Academic Publishers, Dordrecht, pp. 51–65.

Hansen, J.W., Mishra, A., Rao, K.P.C., Indeje, M., Ngugi, R.K., 2009. Potential value of GCM-based seasonal rainfall forecasts for maize management in semi-arid Kenya. Agric. Syst. 101, 80–90.

Hellmuth, M., Moorhead, A., Thomson, M., Williams, J., 2007. Gestion du risque climatique en Afrique: ce que la pratique nous enseigne. Institut National de Recherche pour le climat et la société (IRI), New York, USA, p. 104.

Klopper, E., Vogel, C.H., Landman, W.A., 2006. Seasonal climate forecasts – Potential agricultural-risk management tools? Climatic Change 76, 73–90.

Konte, O., 2007. Méthodologie d'analyse de la performance et d'interprétation des prévisions saisonnières des précipitations (PRESAO): application à la culture du mil au Sénégal. Centre Régional Aghrymet, Niamey, Niger, p. 49.

Lamachere, J.M., 1991. Aptitude au ruissellement et à l'infiltration d'un sol sableux fin après sarclage, vol. 199. IAHS Publ., pp. 109–119.

Luseno, W.K., McPeak, J.G., Barrett, C.B., Little, P.D., Gebru, G., 2003. Assessing the value of climate forecast information for pastoralists: evidence from Southern Ethiopia and Northern Kenya. World Dev. 31, 1477–1494.

Manatsa, D., Unganai, L., Gadzirai, C., Behera, S.K., 2012. An innovative tailored seasonal rainfall forecasting production in Zimbabwe. Nat. Hazards 64, 1187–1207.

Marteau, R., Sultan, B., Baron, C., Traore, S., Agali, A., Moron, V., 2011. The onset of the rainy season and the farmers' sowing strategy for pearl millet cultivation in Southwest Niger. Agric. For. Meteorol. 151 (10), 1356–1369.

Mason, S.J., Graham, N.E., 1999. Conditional probabilities, relative operating characteristics, and relative operating levels. Weather Forecast. 14, 713–725.

Meza, F.J., Hansen, J.W., Osgood, D., 2008. Economic value of seasonal climate forecasts for agriculture: review of ex-ante assessments and recommendations for future research. J. Appl. Meteorol. Climatol. 47, 1269–1286.

Mitchell, T., Jones, P., 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. Int. J. Climatol. 25, 693–712.

Msangi, S., Rosegrant, M.W., You, L., 2006. Ex post assessment methods of climate forecast impacts. Clim. Res. 33, 67–79.

Njau, L.N., 2010. Seasonal-to-interannual climate variability in the context of development and delivery of science-based climate prediction and information services worldwide for the benefit of society. Procedia Environ. Sci. 1, 411–420.

Orlove, B., Roncoli, C., Kabugo, M., Majugu, A., 2010. Indigenous climate knowledge in southern uganda: the multiple components of a dynamic regional system. Climatic Change 100, 243–265.

Patt, A., Suarez, P., Gwata, C., 2005. Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe. PNAS 102, 12623–12628.

Patt, A., Ogallo, L., Hellmuth, M., 2007. Learning from 10 years of climate outlook forums in Africa. Science 318, 49–50.

Phillips, J., Makaudze, E., Unganai, L., 2001. Current and potential use of climate forecasts for resource-poor farmers in Zimbabwe. In: Rosenzweig, C. (Ed.), Impacts of El Nino and Climate Variability in Agriculture. American Society of Agronomy Special Publication, Madison, Wisconsin, pp. 87–100.

Roncoli, C., Ingram, K., Kirshen, P., Jost, C., 2003. Meteorological meanings: understandings of seasonal rainfall forecasts by farmers of Burkina Faso. In: Strauss, S., Orlove, B. (Eds.), Weather, Climate, and Culture. Berg, pp. 181–202.

Roncoli, C., Ingram, K., et Kirshen, P., 2002. Reading the rains: local knowledge and rainfall forecasting in Burkina Faso. Soc. Nat. Resour. 15, 409–427.

Roncoli, C., Jost, C., Kirshen, P., Sanon, M., Ingram, K.T., Woodin, M., Somé, L., Ouattara, F., Sanfo, B.J., Sia, C., Yaka, P., Hoogenboom, G., 2009. From accessing to assessing forecasts: an end-to-end study of participatory climate forecast dissemination in Burkina Faso (West Africa). Climatic Change 92, 433–460.

Roncoli, C., Orlove, B., Kabugo, M., Waiswa, M., 2011. Cultural styles of participation in farmers' discussions of seasonal climate forecasts in Uganda. Agric. Hum. Values 28, 123–138.

Roudier, P. (2012). Climat et agriculture en Afrique de l'Ouest: Quantification de l'impact du changement climatique sur les rendements et évaluation de l'utilité des prévisions saisonnières (Ph.D. thesis). EHESS, Paris, France. p. 189.

Roudier, P., Sultan, B., Quirion, P., Baron, C., Alhassane, A., Traoré, S., Muller, B., 2011. An ex-ante evaluation of the use of seasonal climate forecasts for millet growers in SW Niger. Int. J. Climatol. 32 (5), 759–771.

Salack, S., Muller, B., Gaye, A., 2011. Rain-based factors of high agricultural impacts over Senegal. Part I: integration of local to sub-regional trends and variability. Theoret. Appl. Climatol. 106, 1–22.

Sivakumar, M., 2006. Climate prediction and agriculture: current status and future challenges. Clim. Res. 33, 3–17.

Skees, J.R., Hazell, P., Miranda, M., 1999. New approaches to crop yield insurance in developing countries, EPTD Discussion Paper No. 55.

Sparling, G.P., Ross, D.J., 1988. Microbial contribution to the increased nitrogen mineralization after air-drying of soils. Plant Soil 105, 163–167.

Stoop, W.A., Pattanayak, C.M., Matlon, P.J., Root, W.R., 1981. A strategy to raise the productivity of subsistence farming systems in the West African semi-arid tropics, proceedings sorghum in the Eighties. ICRISAT, Patancheru, India, pp. 519–526.

Sultan, B., Janicot, S., Correia, C., 2009. Medium lead-time predictability of intraseasonal variability of rainfall in West Africa. Weather Forecast. 24, 767–784.

Sultan, B., Barbier, B., Fortilus, J., Mbaye, S.M., Leclerc, G., 2010. Estimating the potential economic value of the seasonal forecasts in West Africa: a long-term ex-ante assessment in Senegal. Weather Clim. Soc. 2, 69–87.

Tarhule, A., Lamb, P.J., 2003. Climate research and seasonal forecasting for West Africans – perceptions, dissemination, and use? Bull. Amer. Meteorol. Soc. 84, 1741–1759.

Thornton, P.K., 2006. Ex ante impact assessment and seasonal climate forecasts: status and issues. Clim. Res. 33, 55–65.

Vaksmann, M., Traoré, S.B., Niangado, O., 1996. Le photo-périodisme des sorghos africains. Agric. Dév. 9, 13–18.

WMO, 2006: Standardised Verification System for Long-Range Forecasts, New Attachment II-8 to the Manual on the GDPFS (WMO-No. 485), Volume I.

WMO, (2013) GFCS – Intergovernmental Board on Climate Services. Special Bulletin 62.

WMO, ACMAD, 1998. Prévision climatique en Afrique, Rapport Tech. 927. African Centre of Meteorological Applications for Development, p. 210.

Ziervogel, G., 2004. Targeting seasonal climate forecasts for integration into household level decisions: the case of smallholder farmers in Lesotho. Geogr. J. 170, 6–21.

Ziervogel, G., Bithell, M., Washington, R., Downing, T., 2005. Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers. Agric. Syst. 83, 1–26.

Zinyengere, N., Mhizha, T., Mashonjowa, E., Chipindu, B., Geerts, S., Raes, D., 2011. Using seasonal climate forecasts to improve maize production decision support in Zimbabwe. Agric. For. Meteorol. 151, 1792–1799.