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Effects of customized climate services on land and labor productivity in Burkina Faso and Ghana

Safiétou Sanfo [a,b,*], Seyni Salack [a], Inoussa A. Saley [a,e], Elidaa K. Daku [a], Nadine O. Worou [c], Arnaud Savadogo [a], Hamadou Barro [a], Samuel Guug [a], Harouna Koné [d], Boubacar Ibrahim [e], Alfredo Rojas [f], Christine Raimond [g], Kehinde O. Ogunjobi [a]

[a] West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Burkina Faso
[b] Université Thomas Sankara, Laboratoire de Developpement Agricole et Transformation de l'Agriculture (DATA), [Laboratory of Agricultural Development and Transformation] Ouagadougou, Burkina Faso
[c] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bamako, Mali
[d] Ministère de l'Agriculture, Département Provincial de Dano [Ministry of Agriculture, Dano Provincial Department], Burkina Faso
[e] Abou Moumouni University, Niamey, Niger
[f] Institut de Recherche Pour le Développement (IRD) [Research Institute for Development], Paris, France
[g] CNRS, France

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ABSTRACT

Climate services favor adopting strategies to increase agricultural productivity, enhance sustainable development, and adapt to unavoidable climate variability and change. However, for climates services to be effective, they must be accessible and suitable to user needs. This study investigated the effects of customized climate services (CCS) on land and labor productivity. Portraying the case of CCS delivered in the districts of Bolgatanga (Northern Ghana), Dano and Ouahigouya (western and northern Burkina Faso) in West Africa, it used: i) historical panel data of daily rainfall, yields, agricultural input, and output prices; ii) cost statements of farm operations and iii) other survey data from beneficiaries of on-farm demonstrations (pilot sites). Different results were found across farmers on the demonstrator sites, with Dano and Bolgatanga recording the best land and labor productivity. Strong and positive effects were observed in Dano, where land productivity increased by 200% and labor productivity doubled despite consecutive pluviometric extremes such as heavy rain events and prolonged dry spells in the 2017 and 2018 cropping seasons. Further investigation showed that CCS was particularly favorable to land and labor productivity of farmers who were committed to the advisory given by the CCS providers. Therefore, as perishable goods, the success of CCS applications would require thorough co-production, delivery, and monitoring for their effectiveness in improving land and labor productivity for agriculture in semi-arid regions of West Africa.

Practical Implications

Climate extreme events are significant threats to agricultural production systems in risk-prone regions such as the Sahel, where environmental challenges are growing (e.g., Jalloh et al., 2013; Niang et al., 2014; Salack et al., 2016, Sultan et al., 2019), yet the need to produce more to feed an ever-increasing and vulnerable population is unequivocal (Beucher and Bazin, 2012). In this region, access to high-quality weather/climate information services is vital for anticipating hydrometeorological risks, for optimizing decisions making of practitioners such as farmers (Gunda et al., 2017; Bliefernicht et al., 2019), and for adapting to climate change. However, some previous experiences have shown that the actual effectiveness of climate information services strongly depends on (i) the accuracy and timeliness of the information provided (Hansen et al., 2006), (ii) the ability of users to access, understand and use them, given the cultural, cognitive, procedural and institutional constraints (Carr et al., 2018; Lugen et al., 2018; Sultan et al., 2020), and (iii) the capacity of end-users to translate the information and knowledge into effective decision-making

* Corresponding author at: WASCAL Competence Centre, Blvd Moammar El-Kahdafi, BP 9507 Ouagadougou 06, Ouagadougou, Burkina Faso.
E-mail addresses: sanfo.s@wascal.org, sanfo.safy@gmail.com (S. Sanfo).

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options (Tall et al., 2014). To that end, they need to be user-centered and site-specific (i.e., customized), integrative of other aspects besides weather/climate information (e.g., technical itinerary), affordable, accessible, and usable by all end-users.

This study investigates the effects of customized climate information services (CCS) on land and labor productivity in Ghana and Burkina Faso. A delivery process is a form of an agroclimatic information package called "AgInfo" (Saley et al., 2020). AgInfo, a newly developed tool, is a short, weekly message addressing farmers whose fields are geo-referenced and the physical features (e.g., surface area, soil type, slopes) are known beforehand. The message contains a seasonal forecast for the next three months, a 24-hour forecast, a deterministic 7-day forecast, and practical instructions (i.e., Technical itineraries). Predictions, based on the analyses of pluviometric extremes, are generated in a single day and are valid for a week. The agricultural practice instructions and technical itineraries consider the type of crop (e.g., maize, millet, sorghum, cowpea), the stage of development, and the predicted weather/climatic events. The AgInfo package also contains verification scores of the forecasts focused on « false starts of cropping season », « dry spells greater than or equal to 10 days,» and heavy rain events considering the three heavy rain categories defined by Salack et al. (2018). Categories 1 and 2 occur most often between weeks 27 and 35 (1 July to 31 August). Category 1 is characterized by a cumulative daily amount varying between 37 and 65 mm, while category 2 has a daily amount above 65 mm/day but below 85 mm/day. Category 3 is challenging to predict and occurs between the 28th and 38th week of the year (10 July to 22 September). It is the most damaging category of heavy rainfall and is identified by rainfall rates exceeding 85 mm/day. The AgInfo package is transmitted by voicemail to users through their mobile phones with language options for Mooré, Dagara, Fara-Fara, French, and English.

After it is transmitted to the farmers, the AgInfo package is monitored and evaluated through an Agro-climatic field school (AFS) animation. The AFS is a personalized interview session (via telephone or face-to-face) with the user on the content of AgInfo (see Table of an example of AgInfo bulletin), and other aspects not found in the package, including trend and variability (past/future) of the locality, downscaled climate information, crop pests, and diseases, etc. They are organized one month before the planting, two months after sowing, and one month after harvest.

In addition, the farmer participates in verifying the quality of the AgInfo package immediately (after its reception) and during the AFS sessions. This permanent interaction between the production team of the AgInfo service and the beneficiaries makes it possible to verify and improve the cases of failure and document the instances of success. Farm operations cost statements were used to collect *in situ* data on crop yields, input prices, and best practices in Bolgatanga (Ghana), Dano and Ouahigouya (Burkina Faso). Using the added value approach, land and labor productivity were computed. To better differentiate between the effects of CCS and those of a good cropping season (Vaughan et al., 2019; Tall et al., 2018), historical data from normal cropping seasons were used to build a baseline scenario. The experimented plots' land and labor productivity in each study area were compared to that of the baseline scenario, and changes were summarized. Our findings demonstrated that land and labor productivity were higher in Dano and Bolgatanga than in Ouahigouya. In Dano, beneficiaries have successfully followed the guidelines and the recommendations provided by CCS. The rigorous application of CCS, particularly AgInfo, has led to significant yield gains. Therefore, the success of CCS in the Sahel will likely require more commitment.

1. Introduction

Climate information services promote resilience to climate change and variability at the national and regional levels and support the transformation value chain in the rainfed farming system in West Africa. Rainfed subsistence farming is an essential asset for food crisis alleviation in rural areas of West Africa. At the same time, high agricultural land and labor productivity are critical to the overall process of sustainable growth and socio-economic development (Zidouemba and Gerard, 2018). However, despite the extremely important contribution of subsistence farming to national income and employment, it remains poorly equipped, poorly financed, and is still very vulnerable to climate variability and change. Particularly in the Sahel, climatic risks and vulnerabilities are becoming increasingly significant (Salack et al., 2015). The recent rainfall regime presents mixed patterns of pluviometric extremes such as heavy rain events, delayed onset and early cessation of the cropping season, long dry spells, seasonal droughts, and floods (Salack et al., 2016; Taylor et al., 2017; Salack et al., 2018). These pluviometric extremes (Salack et al., 2016) are causing considerable crop yield losses and severely affecting land and labor productivity and rural household incomes (Roudier et al., 2011; Sultan and Gaetani, 2016; Sanfo et al., 2017). For instance, according to the Ministry of Agriculture of Burkina Faso, false and delayed onsets of the cropping season, long dry spells, and early cessation of the 2007 rainy season caused crop failure. They led to a food shortage that put more than 600,000 people in severe food insecurity (MAAH, 2017).

To adjust their farming system to the increasing climate-related challenges, farmers of the region have developed by themselves some sets of indigenous techniques of soil and water conservation (SWC) including "Zaï", "half-moons", and "stone bunds" (Zougmoré et al., 2014; Ackermann et al., 2014). These adaptation measures have enabled farming communities to withstand long series of varying weather and climate shocks in the past. However, under the effect of the high amplitude and frequency of the changes in the regional climate, these indigenous practices are becoming less reliable and less efficient in sustaining the land and labor productivity (Barry et al., 2008). Therefore, the future projections are more alarming about the average climate signal and weather and climate extreme events in the 21st century (Ramirez-Villegas and Thornton, 2015; Salack et al., 2015; Sultan and Gaetani, 2016; Faye et al., 2017). For example, it was hypothesized that at a warming rate close or equal to +2 °C, agricultural production, land, and labor productivity are likely to decline significantly across the Sahel and West Africa in general (Sultan et al., 2013; Sultan et al., 2019).

NGOs, research centers, and policymakers have also developed adaptation measures supporting improved productivity to spur farmers to alleviate the adverse effects of increasing climate variability. Commonly used criteria include crop diversification, mixed crop-livestock systems, new crop varieties, and climate services. The latter has been widely debated in the literature, with various definitions adopted across different providers and brokers of these services (Brasseur and Gallardo, 2016). Most recently, the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) defined climate services as "*the provision of information, engineering solutions, policy guidance, and knowledge to support resilience, sustainable development and improve livelihoods. These are "customized" and "integrated" services meeting user needs and the new challenges posed by global warming and climate change, and bringing together human skills, financial investments, information resources, tools, and training to improve the adaptive capacity of nations and the resilience of different sectors*". However, there is standard agreement among all existing definitions as reported by that climate services need to be user-centered and site-specific (customized), integrative of other aspects besides weather/climate information (e.g., Technical itinerary), affordable, accessible, and usable by all end-users.

Innovation through customized climate service (CCS) is a potentially powerful way to assist decision-making and develop farmers' specific adaptive capacities (Lugen et al., 2018; Ouedraogo et al., 2018). However, despite the tremendous efforts of development actors, research organizations, and meteorological services to make climate services more reliable, available and accessible, their use by farmers in the region remains low. The effective adoption of climate services has been exposed to many constraints, including access to markets and credit, farmers' risk awareness, and household income levels (Damba et al., 2018; Vaughan et al., 2019; Sanfo et al., 2020). All these constraints do not address the suitability of climate services to user needs. According to Carr et al. (2017), the starting point for making effective climate services is attention towards potential users and their particular needs by looking into how climate services are helpful in their lives. Vaughan et al. (2019) reviewed studies that have addressed climate services and agricultural production in Africa. According to Vaughan et al. (2019), the studies focused on the types of services that can guide farmers' agricultural production decisions, the climate's quality, and the channels and processes by which African farmers use these services. Out of the 66 studies, 26 concerned West Africa, and only 11 targeted Burkina Faso and 4 Ghana. These 11 studies in Burkina Faso and the four in Ghana focused more on the general economic interest of seasonal forecasting (Dabire et al., 2011), the importance of good climate information in conflict prevention in pastoralist areas (Rasmussen et al., 2014; Rasmussen et al., 2015; Mertz et al., 2016), smallholder farmers' willingness to pay for climate services (Zongo et al., 2015; Ouédraogo et al., 2018) and the access to, perception, dissemination, use, and adoption of climate services (Tarhule and Lamb, 2003; Roncoli et al., 2009; Wood et al., 2014; Oyekale, 2015; Anuga and Gordon, 2016; Limantol et al., 2016). None of these studies addressed the value of providing farmers with – in addition to climate information – customized advice and services to assess the effects of these climate services on land and labor productivity. The next point is that climate services are likely to be used when they are user-friendly, tailored, cheap, accessible, and reliable (Carr and Onzere, 2018; Cash et al., 2003; Hansen et al., 2011; Pagano et al., 2001; Roncoli et al., 2009; Vaughan et al., 2019).

In this paper, CCS is defined as the provision of site-specific weather/climate information, embedded with technical itineraries adapted to crop type, crop growth stage, farm topography, and the user's native language, indigenous knowledge and practices. Can climate services be customised enough to fit and satisfy the specific needs of smallholder farmers? What are the effects of CCS on land and labor productivity? Using participatory and proactive approaches, thorough two-year investigations (2017–2018) were conducted at three pilot sites spread across Burkina Faso and Northern Ghana. Panel data of daily rainfall, crops yields, and agricultural input and output prices were collected from farm operations cost statements, on-farm demonstrations (field trials) of practical CCS delivery involving farmers, weather services, the National Institute of Statistics and Demography (Institut National des Statistiques et de la Demographie [INSD]), and the Ministry of Agriculture of each country. We used operating accounts to collect *in situ* data related to farming operations, including the quantification of farm labor. As the use of climate services is much linked to decision-making and the management of farm costs, we choose to make calculations based on added value involving gross margins and intermediate consumption, which is more plausible than the use of econometric models (Vaughan et al., 2019). An in-depth description of the study area, experiments, and methods used to quantify land and labor productivity are detailed in Section 2. The results are discussed in Section 3. The last section concludes by discussing the study's implications for economic policy.

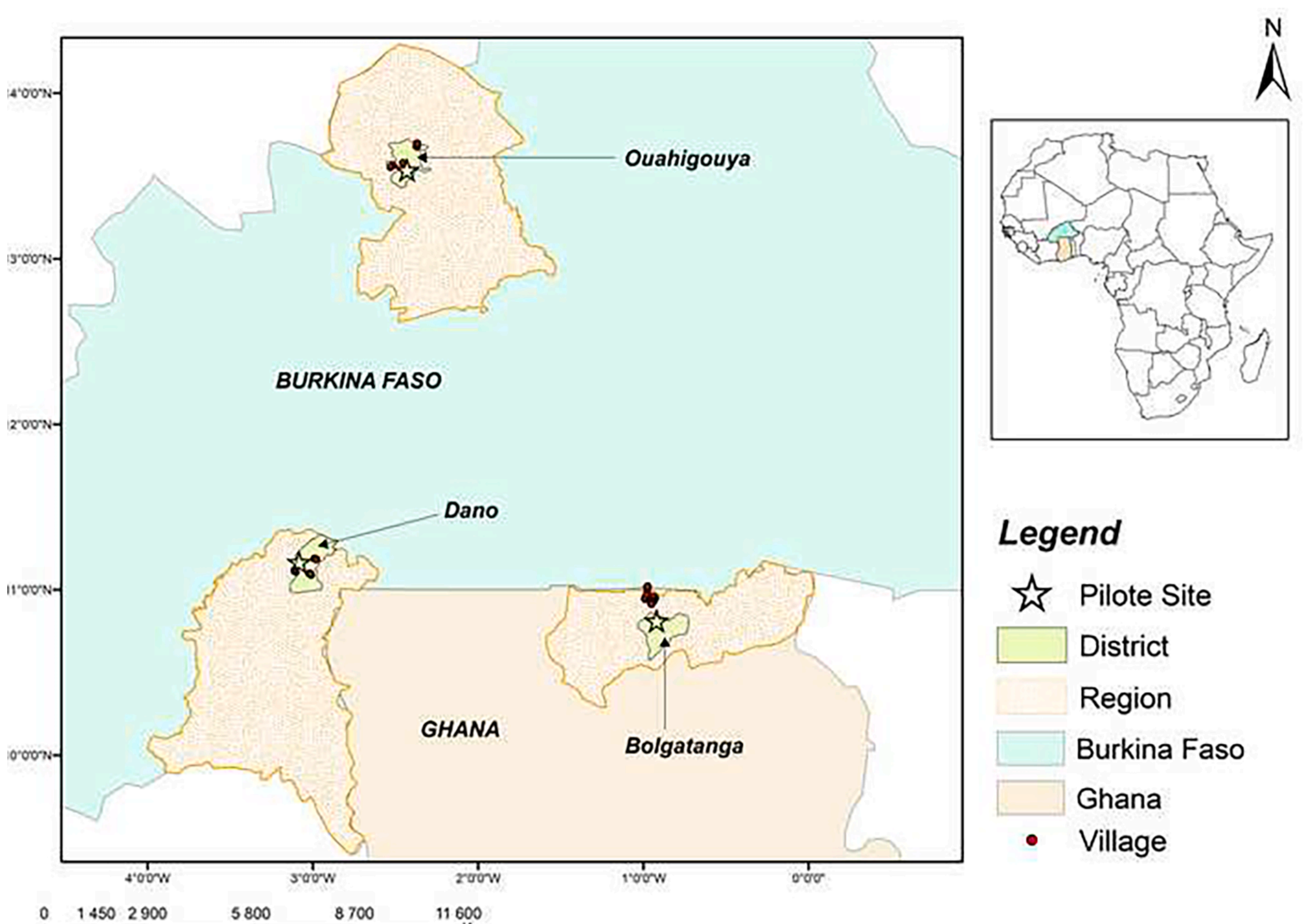

Fig. 1. Location Map of Bolgatang, Dano and Ouahigouya.

2. Study areas and method

2.1. Study areas

The study was conducted across nine villages randomly selected from Bolgatanga in northern Ghana and Dano and Ouahigouya in Burkina Faso (Fig. 1). In these selected rural districts, farmers make little use of climate information (Roncoli et al., 2009; Carr et al., 2017). For example, according to a recent study conducted in Dano and Ouahigouya, only 10% of farmers in Dano and 30% in Ouahigouya use climate information (Damba et al., 2017; Sanfo et al., 2020). Other studies have shown that farmers have little access to climate information (Ouedraogo et al., 2018) due to little media (e.g., radio and television) or smartphones. Moreover, women farmers often have to make long daily journeys to fetch drinking water, firewood and prepare food. Those women, who are too busy with housework and raising children, have little time to listen to the radio or watch television.

Bolgatanga is one of the nine districts and the capital of the Upper East Region of northern Ghana. Its population was estimated at 129,696 inhabitants in 2010 (Ghana Statistical Service [GSS], 2014). The majority of the population (92.2%) is engaged in crop farming. Off-farm jobs are rare but include mining, painting, and work at repair shops and informal metal-working companies. Like in Dano and Ouahigouya, two seasons can be found in Bolgatanga: the wet season, which lasts for six months, and the dry season. The primary staple food crops are corn, millet, sorghum, and rice, and the cash crops include cowpea and groundnut. Both staple foods and cash crops are rainfed and grown during the wet season. However, rainfall varies greatly (Figs. 2 and 5), and extreme pluviometric events are ever more frequent with few cropping strategies implemented. Therefore, flood recession agriculture is the most-used adaptation strategy in northern Ghana (Sidibe et al., 2016; Balana et al., 2019). The region is endowed with fertile floodplains across the White Volta river basin, where flooding occurs annually, mainly in the months of August to early October. Floods increase residual soil moisture and deposit soil nutrients on the floodplains, extending farming activities beyond the traditional growing season.

Dano is the capital of Ioba province in the southwest of Burkina Faso. It has an estimated population of approximately 11,153 inhabitants (INSD, 2018). In 2012, the annual growth rate of the population was estimated at 3% (INSD, 2018). The population density (70 inhabitants per square kilometer) is higher than the average countrywide population density (50 inhabitants per square kilometer) (Sanfo et al., 2017). Agriculture is the region's main activity, but many young men and, more recently, women and young girls are also heavily involved in mining gold. Although artisanal gold mining entails many health risks, such as high blood pressure, coughing, and renal failure, it serves as an off-farm activity for communities. The wet season lasts only six months, from May to October, and the dry season runs from November to April, and the average annual rainfall is about 850 mm. Dano has been increasingly experiencing pluviometric anomalies (Salack et al., 2020). Long dry spells and heavy rain events have increased significantly in the recent cropping seasons (Figs. 2 and 5). These pluviometric extreme events are harmful to rainfed crops and lead to low land and labor productivity (Barron et al., 2003). The main staple crops include sorghum, corn, millet, sesame, groundnut, cotton, and cowpea. Cotton is a cash crop which production benefits from chemical fertilizers distributed by the national cotton company. The farming system relies much on indigenous knowledge and practices such as stone bunds as climate change adaptation strategies (Sanfo et al., 2017). Other examples of indigenous knowledge practices, such as Zaï and half-moon, are less used.

Ouahigouya is located in the Sudano-Sahelian agro-ecological zone in the province of Yatenga in northern Burkina Faso. The municipality is

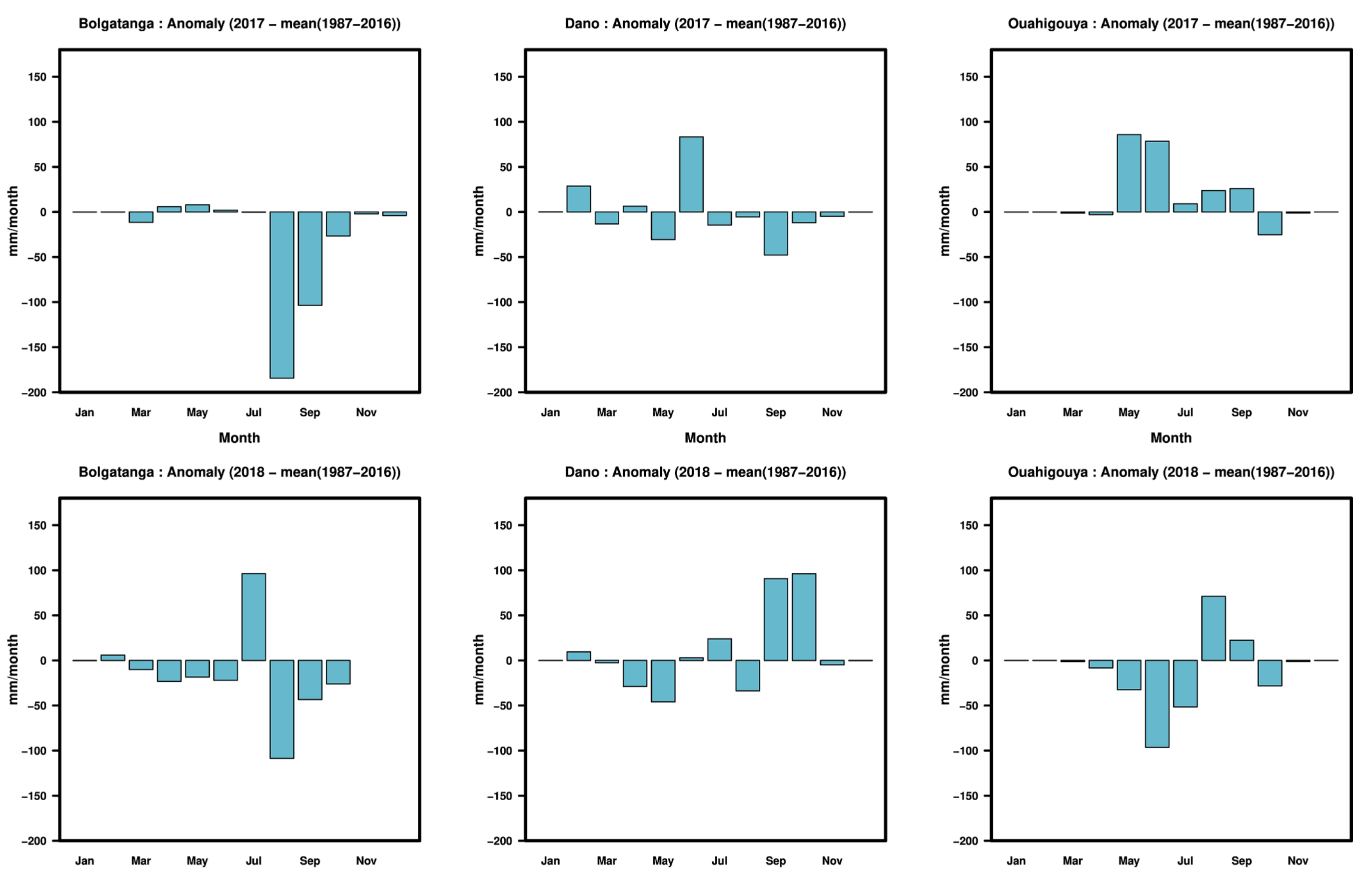

Fig. 2. Monthly anomaly (2017/2018 – mean (1987–2016)) of total rainfall amount for Bolgatanga, Dano and Ouahigouya.

situated between the isohyets 600 mm and 700 mm with a short rainy season and a long dry season that lasts for seven to nine months. In the area, the agro-pastoral farming system is dominated by millet/sorghum as staple crops, constrained by rainfall variability and anomalies (Figs. 2 and 5) and degradation of arable land. Rapid population growth causes demographic pressure on land use which contributes to land degradation. In 2017, the population of Ouahigouya was estimated at 169,893 inhabitants (2017 INSD projection). Ouahigouya does not produce cotton, but sesame, cowpea, and groundnut are the main cash crops. Long dry spells are the primary source of vulnerability for the population, and most farmers are impoverished (Dixon and Holt, 2010). New varieties of seeds, soil water conservation techniques (e.g. "stone bunds", "Zaï", "half-moons"), organic manure amendments, changes in planting dates, floodplain farming, and market gardening are the main adaptation measures used in northern Burkina Faso (Barbier et al., 2009).

2.2. Sampling, data Collection, Co-production, and delivery of CCS.

Household, farming systems, and market data from various sources were acquired in different steps. First, we used expert interviews and investigations from the national institutions of statistics in Burkina Faso and Ghana (e.g., INSD), the Ministry of Agriculture (Burkina Faso), and the Ministry of Food and Agriculture (Ghana) to collect information and secondary panel datasets on production factors (land, labor, and capital), yields, and markets (access and prices). Additionally, nine focus group discussions –FDGs- (3 in each demonstration site) of 120 farmers were used to identify communities vulnerable to heavy rain events, soil erosion, long dry spells, and floods. The choice of FGDs participants was based on three criteria: i) the participating farmer has a next of kin enrolled in at least high school who can assist in the verification of the use, the co-monitoring and co-evaluation of the CCS; ii) the participating farmer has owned farmland for at least five years (e.g., in some cases, the concept of land ownership is limited to the farmers' ability to cultivate the farmland for at least the next five years); and iii) the farmland presented at least one of the following characteristics: high erosion potential due to runoff (steep-slope), high waterlogging potential (down a sloped field with poor drainage), or highly degraded arable land (depleted soil nutrients). In each district, three communities were selected: Tambiri, Pontieba, and Soriane in Dano; Tougzague, Aorema, and Bembla in Ouahigouya; and Bongo Soe, Lungu, and Sumbrungu in Bolgatanga. Although women in the study areas play a crucial role in agricultural activities, they have little decision-making power. Therefore, when groups are required to attend meetings and workshops, men often participate more than women. However, during the FGDs, special attention was focused on the participation of women, which led to 33% attendance for women volunteer farmers.

In total, 120 farmers were selected, of which 60 farmers received CCS – their farms were used to conduct trials demonstrating a near-real-time application of CCS over the 2017 and 2018 rainy seasons (subsequently called "treatment farmers") – and 60 others did not receive CCS – they formed the control group (subsequently called "control farmers"). Topographic surveys and geo-referencing were conducted to delineate the experimental plots and map typical problems (e.g., erosion, waterlogging) of each experimental field that the CCS would seek to resolve. The demonstration plots consisted of a ¼ hectare surface area taken from the total farmland of each "treatment farmer", covering the degraded portions of land. Similarly, ¼ hectare of the total farmland of each control farmer was used as a control plot. The vast majority of these experimental plots were easy to access, close to homes, marketplaces, roadsides, village playgrounds, schools, and churches for showcasing and disclosure to the public.

In the second step, additional household surveys were conducted. Primary data and information were collected on farmers' perception of pluviometric extremes, production factors (land, labor, and capital), yields, markets (access and prices), income off-farm activities, and consumption. These household datasets helped build the baseline scenario. The third step concerned the operationalization of the CCS in the form of the agro-climatic information package (AgInfo) applied on the demonstration plots. AgInfo is a package of climate information (e.g., 3-monthly seasonal forecast, 24-hour and 7-day forecasts) embedded with technical itineraries and adapted advisory (e.g., "start sowing on 12 June"; "sow corn and sorghum at a row spacing of 80 cm × 40 cm"; "construct drainage system in washed hydromorphic soils", etc.) to guide the implementations on the individual experimental plots (See Table 1). The package is disseminated by voicemail via farmers' mobile phones in five languages (i.e. Mooree, Dagaree, Frafra, English and French). With their mobile phones and own rain gauges, farmers and extension agents provided on-the-fly feedback to enable verification of the weather information embedded into the AgInfo package. In support of the practical implementation of the package, small on-farm soil water conservation techniques and anti-erosion structures (e.g. stone bunds, half-moons, Zaï, ridge planting, drainage channels) were constructed to mitigate the adverse effect of extreme pluviometric events on yields on highly exposed plots.

Additional specific needs of individual treatment farmers were identified in participatory workshops, called agro-climatic field schools (AFSs), involving climate scientists, agricultural extension agents and the farmers. The workshops were intended to exchange with the farmers to increase their knowledge on climate information types, the meaning and usage of rain gauges. This helped train the farmers in weather observations and report similar results achieved in other parts of the world. The workshops equally helped the farmers use climate information to choose practical farming techniques (Stigter et al., 2013; Lugen et al., 2018). AFS sessions were undertaken three times a year. During the pre-onset AFS sessions, the experimental plots were prepared two months before the rainy season. Participants were divided into sub-groups per village for better assimilation and practical hands-on activities in observation, discussion, and decision-making on each experimental plot (Bliefernicht et al., 2019). The pre-onset AFS sessions also communicated the results of the seasonal forecast consensus, provided climate change knowledge, discussed and documented indigenous climate knowledge and disaster management techniques of the farmers in case of pluviometric extremes, and provided farmers with manual rain gauges.

During the cropping season, AFSs were conducted at least 30 days after sowing in monitoring and assessment sessions to adjust and correct false starts in the cropping calendar activities. The third AFS session occurs after harvest and before the onset of the next cropping season. Technicians, scientists and farmers meet and fam results are presented. The results of the previous season are assessed, yields are measured and practices are evaluated. Difficulties and failures are also assessed, lesons learnt and successes encouraged. The AgInfo package was continuously delivered to the treatment farmers, and agricultural extension agents ensured that the package was properly applied on the experimental plots by the farmers. For instance, during the 2017 cropping season, some advice was given to treatment farmers whose farmland experienced waterlogging problems. According to the participatory diagnosis with the farmer, confirmed by the first rains, the site was experiencing a temporary waterlogging issue linked to capillary rises. The phenomenon had already been reported in the previous season and had caused a large part of the field to be asphyxiated. The plot was managed for corn and cowpea production. Drainage channels were constructed to evacuate excess water during heavy rain and capillary upwellings. This infrastructure aims to keep the bulk of the plant's root system out of the soil profile susceptible to waterlogging while retaining sufficient moisture for plant development. The drainage channels were opened and closed based on the forecasts given by AgInfo. If AgInfo did not forecast rainfall within four days, the drainage channels remain closed to conserve soil moisture. On the contrary, if AgInfo predicted rainfall, the drainage channels were opened to drain off the excess water. The control farmers did not receive the AgInfo package.

Finally, over the two-year testing of the CCS, data, and information

Table 1
AgInfo issued for pilote sites on 17 July 2018, 18: 00 (GMT). Valid for the period 18–24 July 2018, 18:00 (GMT).

Site	Days-After-Sowing (DAS)	Prediction (Jun-Jul-Aug)	Forecast (24-h)	7-day Forecast			Technical Itinerary (Instructions)
				Date (skill score)	Dry spells (≥9 Days)	Heavy rain events (Category 1, 2, 3)	
Dano	26 ± 6	Above Normal	No rain	Thursday Afternoon (70%); Friday Evening (70%); Sunday Evening (70%)	None	Category 2	Spreading N-P-K fertilizer, armyworm vigilance
Bolgatanga	43 ± 5	Normal	Rain	Thursday Afternoon (70%); Friday Evening (70%); Dimanche Evening, 70%	None	Category 1	Spreading Urea 2nd weeding
Ouahigouya	15 ± 5	Above Normal	Rain	Thursday Afternoon, 60%; Sunday Evening, 60%	None	No signal	1st weeding, armyworm vigilance

were collected on agricultural outputs (crop yields, land, labor, fertilizers, seeds, input and output prices, and income) through direct measurement and observations, as well as individual farm operations cost statements for all the selected farmers. Yields were measured by a yield square device (two square meters) repeated twice on the same plot. These squares were arranged randomly. The grains are then collected, dried, and weighed. The average is then estimated and extrapolated to the hectare. These supplementary yield data were compared against the baseline scenario data to assess the control farmers' agricultural performance and treatment farmers.

2.3. Method of calculating performance indicators

The production factors to account for in measuring agricultural productivity have always been the subject of debate and controversy (Cachia, 2017). Some argue that land is the single most relevant production factor (FAO, 2017). According to these authors, the land factor is directly related to agricultural production, yields and thus ensures food security (Hollinger and Staatz, 2015; Schreyer, 2001). On the other hand, others believe that capital and labor factors are essential (Cachia, 2017; Dharmasiri, 2012). In this investigation, the economic performance indicators consisted of land and labor productivity. In economics, productivity is the product per unit. The labor factor is crucial because it determines the income of farm households and profoundly affects the farming population's standard of living and national prosperity. The capital factor was given little attention because it is intrinsically linked to the production process. Indeed, capital is used to purchase inputs (fertilizers, irrigation, machinery, seeds, and agricultural land). Like production factors, measuring agricultural productivity is also the subject of lively debate. Several methods have been used to quantify agricultural performance (FAO, 2017; Dharmasiri, 2012). Among these methods, there are econometric estimation models of production relationships, non-parametric models, growth accounting techniques, and various index methods (Dharmasiri, 2012; Cachia, 2017). These models and indices require a lot of data and are difficult to assess with simple farm household data (Dharmasiri, 2012). We have opted to use the added value approach, making it possible to estimate the income generated by work or one hectare of land (Barbier et al., 2001; FAO, 2017). The added value is the gross outputs less intermediate inputs. The added value approach makes it possible to account for all the information necessary for production and is, therefore, more important than the gross margin. Land productivity is the added value generated by one hectare of the crop (added value / total area of the corresponding crop). Labor productivity is the added value generated by a worked day (added value/number of workers × days). To avoid confusing the benefits of the CCS and the influence of good weather conditions (Vaughan et al., 2019), a baseline scenario was built based on data from normal cropping seasons. National weather agencies classify seasons according to normal, below, or above normal (i.e. normal is the 1981–2010 average). Any season receiving less than 90% of the 1981–2010 average rainfall is "below normal" , whereas a season ranging from 90% to 110% of the 1981–2010 average rainfall is "normal", and a season ranging from 111% to 150% of the 1981–2010 average rainfall is "above normal". A season that records greater than 150% of the 1981–2010 average rainfall is a "highly above normal". Using the World Meteorological Organization (WMO) climatological classification method, analysis of rainfall data collected from meteorological services helped identify normal cropping seasons over the previous 30 years (1987–2016). We built a new corresponding dataset on crop yields and prices of agricultural inputs and outputs of the identified normal cropping seasons. Data analysis helped us calculate land and labor productivity for the baseline scenario (i.e. average over 30 years of normal rainy seasons) for each study site in order to consolidate the choice of treatment and control farmers. The prices used to measure output are local market prices. For each farm, the required number of workers per day to grow one hectare of crops was assessed.

3. Results and discussion

3.1. Baseline Scenario: The performance narrative of control farmers and treatment farmers

Households had varying social strata and origins, but widespread poverty affected everyone in the form of difficult access to basic services such as clean water, health services, markets, roads, and transportation. There were different levels of household exposure to economic and food insecurity following pluviometric extremes and other abilities to cope with these extreme events. In a normal cropping season land and labor productivity varied depending on the site, although productivity was still very low. The differences in productivity depend on the complexity of farmers' decisions under different constraints: financial, human, and access to natural resources, the necessity of meeting family needs (equipment, access to credit, cash, and food expenditures). Moreover, the opportunities related to labor, and land allocation to various activities explained the variability in land and labor productivity.

Across the sites, both selected control farmers and treatment farmers were the most vulnerable to pluviometric extremes and had similar land and labor productivity. In Bolgatanga, the land productivity of corn was about US$39.44 per hectare, and labor productivity was estimated to be US$0.56 per workday (Figs. 4 and 5). While the control farmers cultivated more than 3 ha per year, the treatment farmers cultivated less than 2 ha. The control farmers were less constrained by cash than the treatment farmers. The control farmers used much more fertilizers, animal traction for tillage and weeding, and hired farmworkers during peak labor periods.

In Dano, both control farmers and treatment farmers cultivated rice, corn, and cowpea. Land and labor productivity varied according to crop type, with corn estimated at US$467.0 per hectare and US$6.89 per day worked, respectively (Figs. 4 and 5). On average, the control group of farmers cultivated 2.3 ha with a family size of nine persons. The treatment group of farmers had an average family size of eight persons and cultivated 1.8 ha. Both treatment and control farmers reported that they faced pluviometric extremes such as long dry spells and floods combined with violent winds.

The farming system in Ouahigouya recorded low land and labor productivity. On average, farmers cultivated very small farmlands (1.6 ha). For instance, the land and labor productivity of cowpea for both "control" and "treatment" farmers was estimated at US$52.65 per hectare and US$1.38 per day worked, respectively (Figs. 4 and 5). The control farmers had larger families with an average of 23 persons. All surveyed farmers were victims of flood events, violent winds, and long dry spells. They adopted strategies (e.g., "Zaï", "half-moon", "mulching", and new crop varieties) to cope with rainfall extremes. Some of these adaptation techniques were limited and easily disrupted by heavy rain events. However, farmers tended to blame most of the failure on a lack of capital (Damba et al., 2018).

3.2. Impacts of the CCS

The CCS delivered during this investigation was the distribution of the AgInfo package and its operationalisation in experimental plots of the treatment farmers. The CCS had a strong positive impact on land and labor productivity of corn, cowpea and sorghum. Compared to the baseline scenario, the 2017 and 2018 cropping seasons were classified as "bad rainy seasons" according to the farmers and agricultural extension agents due to the weather characteristics, and were confirmed by the weather data analysis (Fig. 6). Indeed, data analysis showed that the 2017 and 2018 rainy seasons recorded more rainfall extremes than the cropping seasons of the baseline scenario and the normal average season

Fig. 3. Land Productivity (a) Bolgatanga, (b) Dano, and (c) Ouahigouya.

over 1981–2010. The seasonal total amount of rainfall and the number of rainy days were lower with post-onset and post-floral long dry spells and heavy rain events (Fig. 6).

In the 2017 cropping season, extreme pluviometric events such as long dry spells and an early cessation of the rainy season (Fig. 5) have led to late crop growth and development, resulting in a grain yield below the expected potential. Although the onset of the season was early compared to normal (Fig. 5b), the cropping season was characterized by an uneven rainfall distribution including a substantial rainfall deficit in the JJA (Jun-July-August) period mainly for Bolgatanga and Dano (Fig. 2), too longer dry spells exceeding two weeks (Fig. 5a) and lower number of rainy days (Fig. 5e). Moreover, an invasion of armyworms led to unforeseen expenditures (purchase of products to treat infested plots). Control plots were exposed to extreme rainfall events, and grain yield, land, and labor productivity were very low (Figs. 3, 4, and 6). With the proper application of the AgInfo package on the experimental plots of the treatment farmers, the negative effect of rainfall extremes was much less significant on the grain yield of corn, sorghum, and cowpea, as well as on land and labor productivity (Figs. 3, 4 and 6). Some treatment farmers had abandoned their plots in the previous cropping seasons due to heavy rain events and waterlogging. Following the years 2017 and 2018, with the climate information and application of the AgInfo

Fig. 4. Labor Productivity (a) Bolgatanga, (b) Dano, and (c) Ouahigouya.

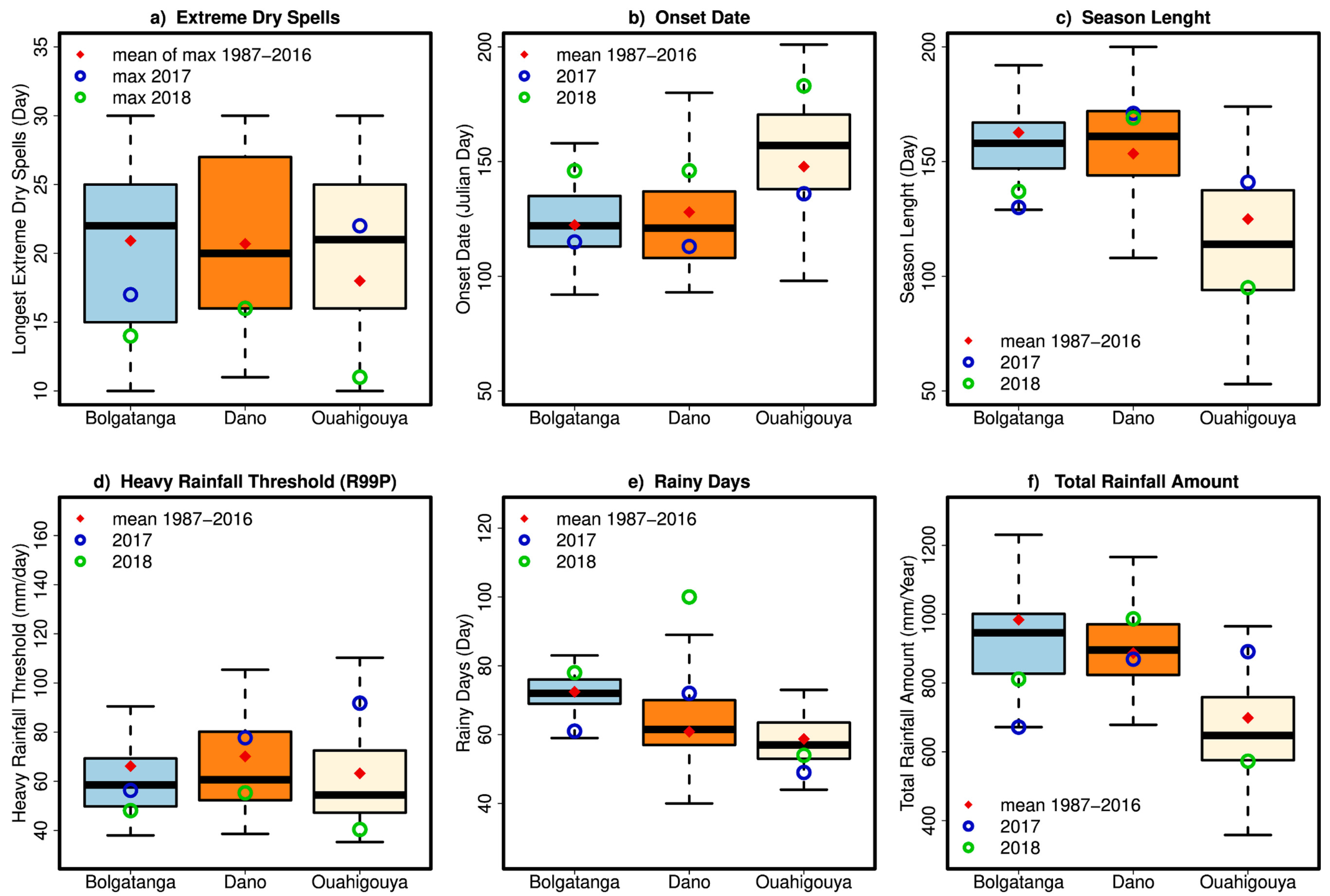

Fig. 5. Historical distribution of some pluviometric extreme events in Bolgatanga (light blue), Dano (chocolate), and Ouahigouya (cornsilk). a) Longest intra-seasonal extreme dry spells (day); b) Onset date (Julian day); c) Season length (day); d) Heavy rainfall threshold (mm/day); e) rainy days (day) and f) total rainfall amount (mm/year). The red-filled diamond represents the mean of the normal year (1987–2016); the circles 2017 (blue) and 2018 (green) represent observed values of each extreme. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

package, farmers had better yields, leading to better land and labor productivity. In Bolgatanga, corn and cowpea yields increased significantly. Compared to the baseline scenario, corn and cowpea results of the treatment farmers increased by 99% and 53%, respectively (Fig. 6). Land and labor productivity of both corn and cowpea also increased by more than 100%. Bolgatanga's results showed that the treatment group of farmers recorded higher yields and higher land and labor productivity than the control farmers. Corn and cowpea yields increased by 111% and 106%, respectively. The corn's land and labor productivity grew by more than 100%, while cowpea increased by 14% and 92%, respectively (Figs. 3 and 4).

In Dano, corn and cowpea yields of the treatment farmers were respectively 241% and 89% higher than those of the baseline scenario (Fig. 6). Moreover, compared to the baseline scenario, land and labor productivity of corn increased by 70% and 38%, respectively, and land and labor productivity of cowpea increased more than 100% (Figs. 3 and 4). Similarly, corn and cowpea's land and labor productivity in the treatment plots was higher than that taken from the control plots (Figs. 3 and 4). Results have shown an increase in land and labor productivity of corn of 298% and 247%, respectively. Land and labor productivity of cowpea increased by 168% and 149%, respectively. These exceptional results can be attributed to applying the AgInfo package on marginal lands that have previously recorded deficient land and labor productivity. For instance, some treatment farmers' plots were eroded or waterlogged with capillary rises. On average, corn and cowpea yields, including land and labor productivity on these plots before the intervention, were very low (Figs. 3, 4, and 6). In Ouahigouya, sorghum and cowpea yields, which increased by 18% and 28%, respectively, were comparable to the baseline scenario (Fig. 6). However, land and labor productivity was negative (Figs. 3 and 4). Although the treatment plots recorded higher yields than the control plots, their land and labor productivity was much lower. Therefore, the increases in sorghum and cowpea yields do not significantly offset the associated production costs, whereas the control farmers used business-as-usual indigenous practices, associated with low capital (Fig. 7).

During the 2018 cropping season, the treatment plots in Bolgatanga and Ouahigouya recorded good yields and good land and labor productivity (Figs. 4, 5 and 7). Crop yields, land and labor productivity, were much better than the baseline scenario. Additionally, crop yields were also higher than the outputs of the control plots. For instance, in Bolgatanga, compared to the control plots, corn and cowpea yields have more than doubled. Land and labor productivity for cowpea increased by 40% and 68% respectively while that of corn have increased excessively (more than 200%). Discussion with farmers revealed that treatment farmers were outraged by the bad performance of the previous cropping season when they were committed to applying the AgInfo package. This phenomenon suggests that farmers underused production factors such as land and labor. Similarly, this is observed in the irrigation system. When rainfed crops fail, farmers tend to invest more in the following dry season (Sanfo et al., 2017). In contrast, although crop yields of the treatment plots in Dano were higher than that of the control plots, the gain in land and labor productivity was much lower (Figs. 3 and 4). Increased market prices of inputs have led to a high cost of improved seeds and organic fertiliser, thus leading to high intervention

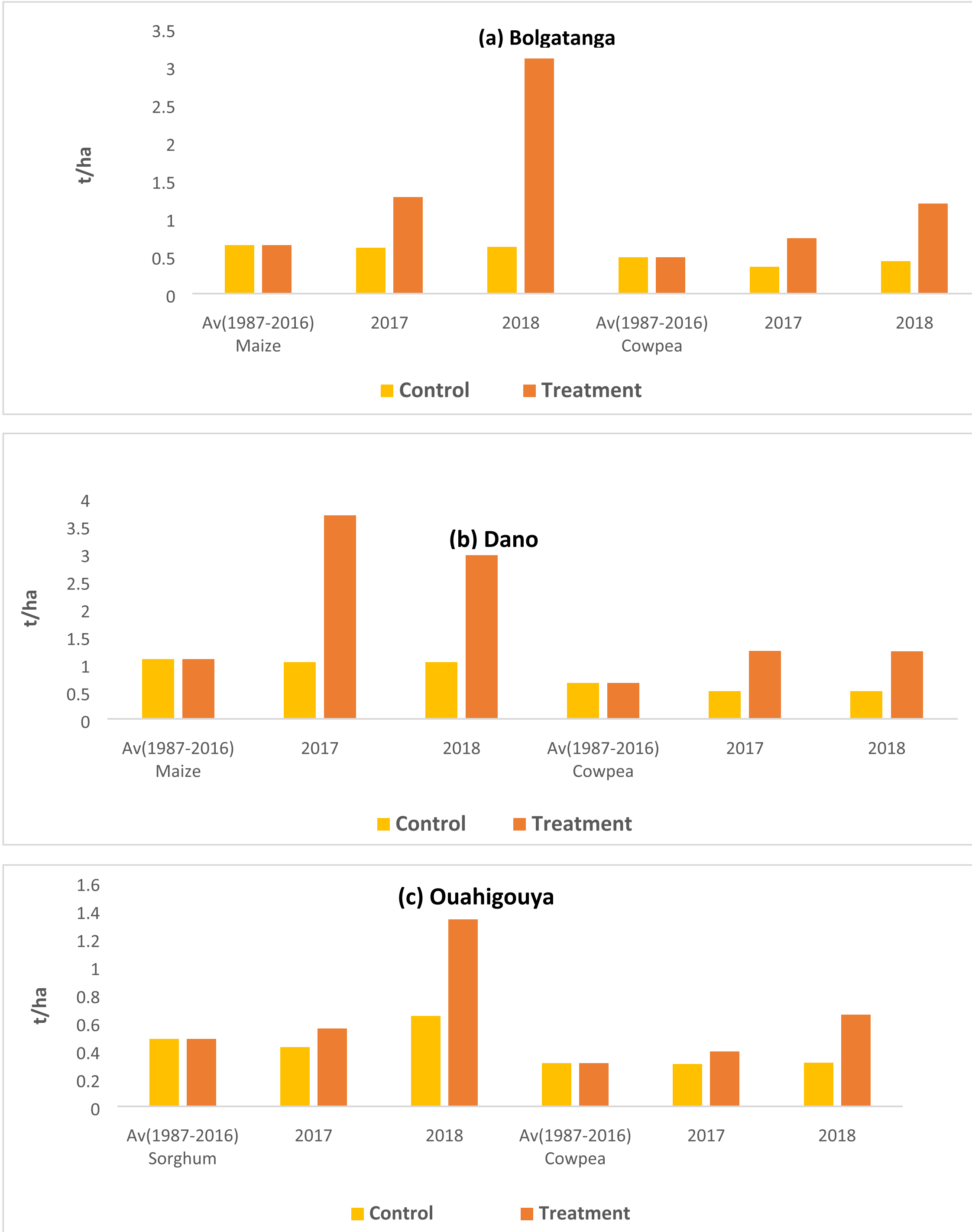

Fig. 6. Yields Statistic (a) Bolgatanga, (b) Dano, and (c) Ouahigouya.

costs (Figure 8). For instance, the market prices of fertiliser rose 11% in the 2018 cropping season (INSD, 2018).

In General, although the results are mixed, the Dano site was most successful, specifically during the 2017 cropping season. During the 2017 cropping season, only one treatment plot showed bad yields with low land and labor productivity. There were several reasons: given the morphology and the topography of the targeted plot (down a slope with capillary rise of water from the water table), corn and cowpea were subjected to a waterlogging effect. Moreover, the farmer concerned did not believe the climate information and advice given by the agricultural extension agents. Consequently, he did not properly implement the technical itinerary as suggested by the AgInfo package (e.g. misuse of CCS, such as failure to take appropriate decisions in order to avoid the fertilisers being washed away by runoff, no respect for the timing of weeding that often led to weed outbreaks). The CCS experiments with the treatment farmers revealed some drawbacks of the process. For example, the practical applications of the AgInfo package in the experimental plots required more time. The farmer allocated the family workforce to different crops and the labor constraint was of great importance (Sanfo and Gérard, 2012). In Bolgatanga, farmers faced difficulties applying the practices suggested by the AgInfo package. They blamed a delayed onset of farm activities (Fig. 6) and still had to face

Fig. 7. Production Costs (a) Bolgatanga, (b) Dano, and (c) Ouahigouya.

challenges with regard to better understanding of the CCS system. In Ouahigouya, performance was very low, showing negative land and labor productivity, i.e., production costs (seeds, fertiliser, labor, and construction of infrastructure) were greater than the gains generated by CCS (Fig. 7). Implementing the instructions contained in the AgInfo package required more training and other interactions, such as several meetings with agricultural extension agents and farmers (Rola et al., 2002). The results of this study did not isolate the effects of climate information but rather the effects of a technology package consisting of climate information and agricultural advice. Even if climate information guides decision-making in agricultural activities (timing of sowing, weeding, and applying fertilizer, type of soil fertility management to be used), the results revealed that the isolated climate information does not guarantee an increase in productivity. The significant reported increase in land and labor productivity was directly tied to the advice (proper use and application of the correct timing of fertilizers, soil restoration, and fertility management upon receiving climate information). Therefore, to make CCS favorable for land and labor productivity, diligent plot monitoring and proper application of the proposed smart practices are necessary. The results suggested that farmers are not yet equipped to exploit climate forecasts without agricultural advice (Tarchiani et al., 2016). These results are in line with many other studies implemented in West Africa whereby many smallholder farmers faced difficulties adopting new technologies because they found them very constraining compared to their traditional practices (Tarchiani et al., 2016; Barry et al., 2008). Decision-making and the associated advice on technical itineraries are crucial in the use of climate information. Delays in decision-making lead to yield losses and lower land and labor productivity. Therefore, smallholder farmers are not ready to abandon their business-as-usual indigenous knowledge in favor of emerging technologies, which they often find inconvenient (Vaughan et al., 2019; Ouédraogo et al., 2018; Ouédraogo et al., 2018). Decision-makers must plan to accompany farmers in decision-making and apply smart practices to enable climate services to fully play their role in managing agricultural risk and improving land and labor productivity.

4. Conclusion and policy implication

This paper explored the effects of CCS on land and labor productivity in West Africa in the context of pluviometric extremes. The field demonstrations were conducted in Bolgatanga (Northern Ghana) and Dano and Ouahigouya (south-western and northern Burkina Faso), to capture both the north–south rainfall variability and the experiences of many smallholder farmers living in semi-arid zones where agricultural productivity is very low and nearly half of the population are poor living on less than US$1 per day. Cropping systems in this region remain subsistence-oriented with very low yields (~500 kg/ha), specifically in the northern part of Burkina Faso. Although each village has peculiarities, we observed that within isohyets 600–800 mm, many households had similar land and labor productivity. Splitting the sample of farmers into control farmers and treatment farmers was done to provide data that would apply to millions of farmers in the same agro-ecological and agro-climatic conditions. The delivery of CCS resulted in increased land and labor productivity for the beneficiary farmers. The mixed empirical results showed that the CCS system was particularly favorable to land and labor productivity at Bolgatanga and Dano. In Bolgatanga and Dano, farmers were more committed to the advice and recommendations provided by CCS. Comparing the results to a relatively recent baseline scenario (1987–2016) was a valid indicator concerning traditional or indigenous practices. However, better operationalization of CCS required more time, as well as advanced monitoring of farms to minimize shortcomings and failures.

Increased pluviometric extremes may likely inhibit the growth of the agricultural sector in West Africa. It may also pose severe threats to the food security of the rural farmers' households unless CCS is scaled up to support a more significant number of communities. The implementation will enable farmers to generate higher income and employment to benefit the rural economy and reduce rural migration. The costs of uninsured agricultural risk are high enough to motivate interventions such as CCS to bolster the efficient management of pluviometric extremes. Additional long-term data will be needed to better asses the effectiveness and efficiency of CCIS at local and larger scales.

CRediT authorship contribution statement

Safiétou Sanfo: Conceptualization, Investigation, Methodology, Validation, Formal analysis, Resources, Supervision, Writing – original draft, Writing – review & editing. **Seyni Salack:** Investigation, Validation, Writing – original draft, Writing – review & editing. **Inoussa A. Saley:** Investigation, Validation, Writing – original draft, Writing – review & editing. **Elidaa K. Daku:** Investigation, Validation. **Nadine O. Worou:** Writing – original draft. **Arnaud Savadogo:** Investigation, Validation. **Hamadou Barro:** Investigation, Validation. **Samuel Guug:** Investigation, Validation. **Harouna Koné:** Investigation, Validation. **Boubacar Ibrahim:** Writing – original draft. **Alfredo Rojas:** Writing – original draft. **Christine Raimond:** Writing – original draft. **Kehinde O. Ogunjobi:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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