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Climate change and agriculture in Burkina Faso

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ABSTRACT

The impacts of climate change (CC) are expected to be higher in developing countries (e.g. Sub-Saharan Africa). However, these impacts will depend on agriculture development and resilience. Therefore, this paper provides a comprehensive analysis of the multifaceted relationships between CC and agriculture in Burkina Faso (BF). A search performed in March 2020 on the Web of Science yielded 1,820 documents and 217 of them were included in the systematic review. The paper provides an overview on both bibliometrics (e.g. journals, authors, institutions) and topics addressed in the literature viz. agriculture subsectors, climate trends in BF, agriculture and CC mitigation (e.g. agriculture-related emissions, soil carbon sequestration), impacts of CC on agriculture (e.g. natural resources, crop suitability, yields, food security) as well as adaptation strategies. BF is experiencing CC as evidenced by warming and an increase in the occurrence of climate extremes. The literature focuses on crops, while animal husbandry and, especially, fisheries are often overlooked. Moreover, most of the documents deal with CC adaptation by the Burkinabe farmers, pastoralists and rural populations. Analysed adaptation options include conservation agriculture and climate-smart agriculture, irrigation, crop diversification, intensification, livelihoods diversification and migration. However, the focus is mainly on agricultural and individual responses, while livelihoods strategies such as diversification and migration are less frequently addressed. Further research is needed on the dual relation between agriculture and CC to contribute to the achievement of the Sustainable Development Goals. Research results are crucial to inform policies aimed at CC mitigation and/or adaptation in rural BF.

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INTRODUCTION

Climate change is considered nowadays as one of the most pressing challenges facing humanity (Intergovernmental Panel on Climate Change, 2012; Steffen *et al.*, 2015; United Nations, 2015). Climate change also represents a threat towards the achievement of the Sustainable Development Goals (SDGs) such as SDG2 “Zero Hunger” (Mugambiwa & Tirivangasi, 2017). Agriculture is, on the one hand, a main contributor to climate change through greenhouse gas (GHG) emissions and, on the other hand, one of the sectors that are most affected by climate change (FAO, 2016; HLPE, 2012). Agriculture, forestry and other land uses (AFOLU) account for about one-fifth of GHG emissions worldwide (FAO, 2016). Therefore, both efforts for mitigation (Bennetzen *et al.*, 2016; Elum *et al.*, 2017; Forabosco *et al.*, 2017; Kim *et al.*, 2016; Minasny *et al.*, 2017; Petersen *et al.*, 2013; van Beek *et al.*, 2010; Zomer *et al.*, 2008) and adaptation (Bryan *et al.*, 2013; Hertel & Lobell, 2014; Loboguerrero *et al.*, 2019; Rippke *et al.*, 2016; Salinger *et al.*, 2005; Suckall *et al.*, 2015) are relevant in the context of agriculture. Indeed, Torquebiau (2017) suggests that “Agriculture is probably the most climate-dependent human activity

and is both victim and responsible for climate change, while it can also be a solution to the climate change crisis”.

Evidence shows that the impacts of climate change (CC) will be high in Sub-Saharan Africa (Baarsch *et al.*, 2020; Bakshi *et al.*, 2019; Bornemann *et al.*, 2019; Hassan, 2010; Lokonon *et al.*, 2019). Changes in climate will affect both temperatures (Faye *et al.*, 2018; Issahaku *et al.*, 2016; Thornton *et al.*, 2011; Waha, Müller, & Rolinski, 2013) and precipitation (Ayanlade *et al.*, 2018; Le Houérou, 1996; Onyutha, 2018a; Waha, Müller, & Rolinski, 2013). Furthermore, as the primary sector still plays an important socio-economic role in the region, climate change will even affect the socio-economic development of these countries (Abidoye & Odusola, 2015; Arndt *et al.*, 2011; Asafu-Adjaye, 2014; Azzari & Signorelli, 2020; Baarsch *et al.*, 2020; Boubacar, 2015; Calzadilla *et al.*, 2013; England *et al.*, 2018; Lokonon *et al.*, 2019; Montaud *et al.*, 2017; Schlenker & Lobell, 2010; Serdeczny *et al.*, 2017). Indeed, agriculture contributes to the population’s food security, and is an important source of income and livelihoods, especially in the rural areas, and a significant contributor to the national gross domestic product

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(GDP) thanks to agricultural exports (Diao *et al.*, 2007; FAO & OECD, 2015). Therefore, it is widely argued that climate change will also impact food security (Belay *et al.*, 2019; Giannini *et al.*, 2017; Hasegawa *et al.*, 2018; Islam *et al.*, 2016; Luetkemeier *et al.*, 2018; Niles & Brown, 2017; Olayide & Alabi, 2018; Onyutha, 2018b; Palm *et al.*, 2010; Richardson *et al.*, 2018) and livelihoods (Aniah *et al.*, 2019; Antwi-Agyei *et al.*, 2014; Asfaw *et al.*, 2019; Brottem & Brooks, 2018; García de Jalón *et al.*, 2017; Gautier *et al.*, 2016; Jones & Thornton, 2009; Kimani *et al.*, 2015; Olayide & Alabi, 2018; Sissoko *et al.*, 2011) in Sub-Saharan Africa (SSA). Climate change is also a driver of migration (Kniveton *et al.*, 2012; Luginaah *et al.*, 2009; Pricope *et al.*, 2013; Ruf *et al.*, 2015; van der Land & Hummel, 2013; Wiederkehr *et al.*, 2018) and an important cause of conflicts (Benjaminsen *et al.*, 2012; Buhaug *et al.*, 2015; Hendrix & Glaser, 2007; International Crisis Group, 2020; Pricope *et al.*, 2013; von Uexkull, 2014) in SSA. In their analysis of climate change impact on development in Africa, Baarsch *et al.* (2020) raise “*issues on the ability of African countries to reach their SDGs targets and the potential increasing risk of instability, migration across African countries, of decreased trade and economic cooperation opportunities as a consequence of climate change exacerbating its negative consequences*”.

Agriculture in SSA, which is predominantly rain-fed, is highly vulnerable to climate fluctuations and droughts (Abdulai, 2018; Adhikari *et al.*, 2015; Asafu-Adjaye, 2014; Barrios *et al.*, 2008; Cooper *et al.*, 2008; Haile *et al.*, 2019; Haile *et al.*, 2018; Kahsay & Hansen, 2016; Lokonon *et al.*, 2019; Muchuru & Nhamo, 2019; Müller, 2013; Muller *et al.*, 2011; Pironon *et al.*, 2019; Rippke *et al.*, 2016; Schlenker & Lobell, 2010; Sidibé *et al.*, 2018; Sonwa *et al.*, 2017; Webersik & Wilson, 2009). Webersik and Wilson (2009) put that “*African economies are closely linked to natural resources and rely heavily on agriculture, largely rain fed [...]. It is predicted that Africa will be particularly vulnerable to climate change and climate variability associated with biodiversity loss, food insecurity, water scarcity and an increase in drought frequency*” (p. 400). Climate change affects particularly smallholder farmers (Boillat *et al.*, 2019; Descheemaeker *et al.*, 2016; Dixon & Stringer, 2015; FAO, 2016; Freduah *et al.*, 2019; García de Jalón *et al.*, 2018; Gbegbelegbe *et al.*, 2018; Lalou *et al.*, 2019; Odame Appiah *et al.*, 2018; Oluwatayo, 2019; Williams *et al.*, 2018). The impacts of climate change on agriculture consists in the reduction of the production and yields of staple crops such as maize (Bedeke *et al.*, 2020; Davenport *et al.*, 2018; Epule *et al.*, 2017; Faye *et al.*, 2018; Freduah *et al.*, 2019; Parkes *et al.*, 2018; Shi & Tao, 2014; Srivastava *et al.*, 2018; Tesfaye *et al.*, 2015; Waha, Müller, & Rolinski, 2013), wheat (Trnka *et al.*, 2019), rice (Akinbile *et al.*, 2015; Daccache *et al.*, 2015; Terdoo & Feola, 2016; van Oort & Zwart, 2018; Zhang *et al.*, 2019), cassava (Jarvis *et al.*, 2012; Pushpalatha & Gangadharan, 2020; Rosenthal & Ort, 2012), sorghum (Akinseye *et al.*, 2020; Elagib *et al.*, 2019; Faye *et al.*, 2018; Mishra *et al.*, 2008; Sultan *et al.*, 2014), millet (Sultan *et al.*, 2013). While most of the studies on the relationships between climate change and agriculture have focused on crop production, especially staple crops, a growing body of research deals with climate change impacts on livestock (Brandt *et al.*, 2018, 2020; Forabosco *et al.*, 2017; Gerssen-Gondelach *et al.*,

2017; Godber & Wall, 2014; Henderson *et al.*, 2017; Houessou *et al.*, 2019; Liverpool-Tasie *et al.*, 2019; Mare *et al.*, 2018; Naah & Braun, 2019; Salmon *et al.*, 2018). There are also more and more studies on the effects of climate change on fisheries in Africa (Bellhabib *et al.*, 2016; Freduah *et al.*, 2019; Lam *et al.*, 2012; Lauria *et al.*, 2018; Limuwa *et al.*, 2018; Nyboer *et al.*, 2019; Thiaw *et al.*, 2017). Many international organisations and scholars highlighted the benefits of climate-smart agriculture (CSA) (Abegunde *et al.*, 2019; Amadu *et al.*, 2020; Andrieu *et al.*, 2017; García de Jalón *et al.*, 2017; Makate *et al.*, 2019; Raile *et al.*, 2019; Totin *et al.*, 2018; Zougmore *et al.*, 2019), conservation agriculture (Boillat *et al.*, 2019; Corbeels *et al.*, 2014, 2019; Dougill *et al.*, 2017; Komarek *et al.*, 2019; Powlson *et al.*, 2016; Thierfelder *et al.*, 2018; Worou *et al.*, 2019) and agroforestry (Corbeels *et al.*, 2019) both for climate change mitigation and adaptation. Indeed, agriculture can also contribute to mitigate climate change by reducing GHG emissions (Bellassen *et al.*, 2010; Suckall *et al.*, 2015; Takimoto *et al.*, 2008; Vågen *et al.*, 2005; van Loon *et al.*, 2019). Loboguerrero *et al.* (2019) argue that “*Climate-smart agriculture can help foster synergies between productivity, adaptation, and mitigation*”. Climate change also affects availability of and access to natural resources such as water (Adnew Degefu *et al.*, 2019), land (Conradie *et al.*, 2019; Marchant *et al.*, 2018) and ecosystem services (Koo *et al.*, 2019; Marchant *et al.*, 2018; Scheiter & Savadogo, 2016). Some scholars argue that climate change impacts will likely be higher on women thus highlighting the need for a gender-sensitive approach in the adaptation to climate change (Bryan *et al.*, 2018; Chah *et al.*, 2018; Djoudi & Brockhaus, 2011; Jost *et al.*, 2016; Onwutuebe, 2019; Rao, 2019).

In the context of SSA, the Sahel and West Africa regions seem particularly vulnerable to climate change (Baarsch *et al.*, 2020). Indeed, referring to the Sahel region, Zhang *et al.* (2019) put that “*the region is vulnerable to unfavorable weather and has a very low adaptive capacity*”. Sultan and Gaetani (2016) highlight that “*West Africa is known to be particularly vulnerable to climate change due to high climate variability, high reliance on rain-fed agriculture, and limited economic and institutional capacity to respond to climate variability and change*”. Therefore, it is expected that the West African countries of the Sahel will be severely hit by climate change. Egbebiyi *et al.* (2019) posit that “*The changing climate is posing significant threats to agriculture, the most vulnerable sector, and the main source of livelihood in West Africa*”. In this context, and referring to a West African and Sahelian country such as Burkina Faso, Zidouemba (2017) argues that the “*economic development in Burkina Faso is potentially vulnerable to climate change, given the country’s dependence on rain-fed agriculture*” (p. 2797). Indeed, Burkina Faso (BF) is considered as one of the most vulnerable countries to climate change in Africa (Busby *et al.*, 2014). BF, a landlocked country in the Sahelian West Africa, has a low Human Development Index (HDI, ranking 182 out of 189 countries) (UNDP, 2019) and is affected by multiple forms of malnutrition (FAO *et al.*, 2018; USAID, 2018). Indeed, the prevalence of undernourishment was 14.1% in 2015–17 period and there were about 3.0 million undernourished people in the country over the same period (FAO *et al.*, 2018). Furthermore, micronutrient deficiencies (e.g. iodine, iron, vitamin A) are widespread in the country (Institut

National de la Statistique et de la Démographie & ORC Macro, 2004; USAID, 2018). Likewise, poverty is widespread as 43.7% of the Burkinabe population lives below the poverty line of 1.90 USD per day (World Bank, 2019). The country should also fill the gap in terms of sustainable development as it ranks 138th out of 157 countries in progress toward meeting the SDGs (Sachs *et al.*, 2017; USAID, 2018). Agriculture is a leading sector in the Burkinabe economy; it contributes to 28.6% of GDP and 28.3% of employment (World Bank, 2019). Staple crops include cereals (e.g. sorghum, millet, maize, rice) and legumes (e.g. cowpea), while groundnut and cotton represent the major cash crops (USAID, 2017). Nonetheless, agriculture is extensive and almost entirely reliant on the summer rainfall (June–September), thus making it particularly vulnerable to CC. Indeed, high rainfall variability characterises the local climate (Mainardi, 2011; USAID, 2017). Therefore, this review paper analyses the state of research on the relation between climate change and agriculture in Burkina Faso. The paper reviews both the contribution of agriculture to climate change in terms of GHG emissions as well as the adaptation of Burkinabe agriculture to the changing climate.

METHODS

The article draws upon a systematic review of records indexed in all databases of Clarivate Analytics - Web of Science (viz. Web of Science Core Collection, Current Contents Connect, MEDLINE®, KCI-Korean Journal Database, SciELO Citation Index, Russian Science Citation Index). The review follows the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher *et al.*, 2009). A search was performed on 23 March 2020 using the following string: (*Burkina OR Sahel OR “West Africa” OR “Sub-Saharan Africa”*) AND (*{climate change} OR “climate variability” OR “global warming”*) AND (*agriculture OR agro OR horticulture OR “animal husbandry” OR “livestock” OR fish*). The literature search yielded 1,820 records.

The methodology used in documents selection was informed by that adopted by El Bilali (2019, 2020). The selection of documents included in the systematic review is described in Table 1. In the context of the present paper, agriculture is

considered to include crop production, animal production and fisheries. Furthermore, while forestry is not considered in the present paper, documents dealing with agroforestry were included in the systematic review. Meanwhile, documents dealing with the impacts of climate change on protected areas, parks and wildlife were excluded. For being eligible for the present systematic review, each document had to meet simultaneously three criteria relating to the topical focus (viz. document deals with both climate change *and* agriculture), geographical coverage (viz. document deals with BF) and the type of document (viz. document is an article, a conference paper or a book chapter; letters to editors, editorial comments and/or notes were not considered). Furthermore, since the paper deals with research on the relationships between climate change and agriculture, only research articles were considered (i.e. reviews were excluded).

Based on the screening of titles, 824 documents were excluded as they do not refer to BF; documents that cover wide geographical areas that include BF (e.g. Sahel, West Africa, SSA, Economic Community of West African States - ECOWAS) were kept for further scrutiny. Further 621 documents were discarded following the analysis of abstracts as they do not meet one or more of the inclusion criteria. For instance, many articles refer to climate change in their introduction but they deal with other topics. Moreover, 258 documents were excluded after scrutiny of full-texts. These also include 52 reviews, systematic reviews and meta-analyses (Abegunde *et al.*, 2019; Agrawal *et al.*, 2014; Belhabib *et al.*, 2016; Biazin *et al.*, 2012; Botha *et al.*, 2020; Brown *et al.*, 2011; Cairns *et al.*, 2012; Carr *et al.*, 2020; Chuku & Okoye, 2009; Corbeels *et al.*, 2019; Druyan, 2011; Epule *et al.*, 2014; Forabosco *et al.*, 2017; Gautier *et al.*, 2016; Gil *et al.*, 2017; Hansen *et al.*, 2011; Hassen *et al.*, 2017; Islam *et al.*, 2016; Katikiro & Macusi, 2012; Kim *et al.*, 2016; Koubi, 2019; Lahive *et al.*, 2019; Lal, 2019; Loboguerrero *et al.*, 2019; Makate, 2019; Mbow *et al.*, 2014; Mngumi, 2020; Muchuru & Nhamo, 2019; Müller, 2013; Muller *et al.*, 2011; Mundia *et al.*, 2019; Mutuo *et al.*, 2005; Nkiaka *et al.*, 2019; Nkrumah, 2019; Partey *et al.*, 2018; Powlson *et al.*, 2016; Pushpalatha & Gangadharan, 2020;

Table 1: Systematic review steps and process

Selection steps	Selected documents number	Number of documents excluded and exclusion reasons
Initial search and records identification	1,820	--
Screening of documents based on titles	1,820	824 documents excluded because they deal with other countries than BF e.g., Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Ethiopia, Ghana, Guinea-Bissau, Ivory Coast, Kenya, Madagascar, Malawi, Mali, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Swaziland, Tanzania, Togo, Uganda, Zimbabwe.
Screening of documents based on abstracts	996	621 documents excluded: <ul style="list-style-type: none"> • 396 documents because they do not deal with BF • 199 documents because they do not address climate change • 26 documents because they don't deal with agriculture
Scrutiny of full-texts	375	258 documents excluded: <ul style="list-style-type: none"> • 105 records because they do not address BF • 87 documents because they don't deal with climate change • 14 documents because they don't deal with agriculture • 52 reviews were discarded
Inclusion of documents in the systematic review	117	--

Ramirez-Villegas & Challinor, 2012; Rhodes & Atewamba, 2019; Roudier *et al.*, 2011; Sarr, 2012; Shcherbak *et al.*, 2014; Sileshi *et al.*, 2019; Snapp *et al.*, 2019; Sultan & Gaetani, 2016; Terdoo & Feola, 2016; Totin *et al.*, 2018; Vaughan *et al.*, 2019; Webber *et al.*, 2014; Wilcox *et al.*, 2019; Williams *et al.*, 2018; Zougmore *et al.*, 2018). Consequently, 117 documents were selected and underwent bibliometric and topical analyses (Table 2).

The systematic review of the selected documents regarded both bibliographical metrics and topical focus of research on climate change and agriculture in BF (Table 3).

RESULTS AND DISCUSSION

Bibliographical Metrics of Research on Climate Change and Agriculture in Burkina Faso

The biblio-metrics (e.g. sources/journals, subject areas, authors, institutions, countries) for research on climate change and agriculture in BF are shown in Table 4.

The analysis of bibliographical data suggests an increasing academic interest in the nexus between climate change and

Table 2: Documents included in the systematic review

Year	Documents number	References
2020	5	Ayantunde <i>et al.</i> (2020); Azzarri and Signorelli (2020); Döring (2020); Prestele and Verburg (2020); Tankari (2020)
2019	22	Quintero and Cohen (2019); Berthou <i>et al.</i> (2019); Belesova <i>et al.</i> (2019); Nelimor <i>et al.</i> (2019); Kamali <i>et al.</i> (2019); Lokonon <i>et al.</i> (2019); Zhang <i>et al.</i> (2019); Serpantié <i>et al.</i> (2019); Pironon <i>et al.</i> (2019); Cobbing and Hiller (2019); Sultan <i>et al.</i> (2019); Zampaligré and Fuchs (2019); Rauch <i>et al.</i> (2019); Egbebiyi <i>et al.</i> (2019a); Egbebiyi <i>et al.</i> (2019b); van Loon <i>et al.</i> (2019); Nyboer <i>et al.</i> (2019); Sidibe <i>et al.</i> (2019); Sultan <i>et al.</i> (2019); Ugbaje <i>et al.</i> (2019); Zouré <i>et al.</i> (2019); Boansi <i>et al.</i> (2019)
2018	30	Bicher and Diedhiou (2018); Bryan <i>et al.</i> (2018); Bunclark <i>et al.</i> (2018); Callo-Concha (2018); Chen <i>et al.</i> (2018); de Vrese <i>et al.</i> (2018); Dimobe <i>et al.</i> (2018); Doelman <i>et al.</i> (2018); Egbendewe (2018); Fanzo <i>et al.</i> (2018); Faye <i>et al.</i> (2018); Ferner <i>et al.</i> (2018); Garcia de Jalon <i>et al.</i> (2018); Garnot <i>et al.</i> (2018); Hasegawa <i>et al.</i> (2018); Henderson <i>et al.</i> (2018); Hoffman <i>et al.</i> (2018); Kamali <i>et al.</i> (2018); Klutse <i>et al.</i> (2018); Olusegun <i>et al.</i> (2018); Onyutha (2018a); Parkes <i>et al.</i> (2018); Rasmussen (2018); Richardson <i>et al.</i> (2018); Sidibé <i>et al.</i> (2018); Steward <i>et al.</i> (2018); Sylla <i>et al.</i> (2018a); Sylla <i>et al.</i> (2018b); Thomas and Nigam (2018); van Oort and Zwart (2018)
2017	30	Andam-Akorful <i>et al.</i> (2017); Asare-Kyei <i>et al.</i> (2017); Belem and Saqalli (2017); Boansi <i>et al.</i> (2017); Choptiany <i>et al.</i> (2017); Dale <i>et al.</i> (2017); Defrance <i>et al.</i> (2017); Egbendewe <i>et al.</i> (2017); Gaisberger <i>et al.</i> (2017); Guan <i>et al.</i> (2017); Hadebe <i>et al.</i> (2017); Henderson <i>et al.</i> (2017); Jahel <i>et al.</i> (2017); Jun (2017); McPeak (2017); Niles and Brown (2017); Ogundari <i>et al.</i> (2017); Oguntunde <i>et al.</i> (2017); Ouédraogo <i>et al.</i> (2017); Palazzo <i>et al.</i> (2017); Rigolot <i>et al.</i> (2017); Sanfo <i>et al.</i> (2017); Serdeczny <i>et al.</i> (2017); Sonwa <i>et al.</i> (2017); Sossa <i>et al.</i> (2017); Tabeau <i>et al.</i> (2017); Torquebiau (2017); Wang <i>et al.</i> (2017); Witmer <i>et al.</i> (2017); Zidouemba (2017)
2016	24	Ahmed <i>et al.</i> (2016); Amjath-Babu <i>et al.</i> (2016); Bennetzen <i>et al.</i> (2016); Bodin <i>et al.</i> (2016); Borona <i>et al.</i> (2016); Callo-Concha (2016); Descheemaeker <i>et al.</i> (2016); Di Leo <i>et al.</i> (2016); Douxchamps <i>et al.</i> (2016); Dunning <i>et al.</i> (2016); Gray and Wise (2016); Hänke <i>et al.</i> (2016); Henderson <i>et al.</i> (2016); Huyer (2016); Mertz <i>et al.</i> (2016); Rippke <i>et al.</i> (2016); Salack <i>et al.</i> (2016); Scheiter and Savadogo (2016); Siebert (2016); Sorgho <i>et al.</i> (2016); Stith <i>et al.</i> (2016); van Wesenbeeck <i>et al.</i> (2016); von Uexkull <i>et al.</i> (2016); Waha <i>et al.</i> (2016)
2015	19	Abidoye and Odusola (2015); Ahmed <i>et al.</i> (2015); Buhaug <i>et al.</i> (2015); Dixon and Stringer (2015); Fonta <i>et al.</i> (2015); Gahi <i>et al.</i> (2015); Guan <i>et al.</i> (2015); Kamoni and Gicheru (2015); Kima <i>et al.</i> (2015); Lebel <i>et al.</i> (2015); Mande <i>et al.</i> (2015); Oyekale (2015); Parkes <i>et al.</i> (2015); Rasmussen <i>et al.</i> (2015); Salack <i>et al.</i> (2015); Sylla <i>et al.</i> (2015); Tesfaye <i>et al.</i> (2015); Thornton and Herrero (2015); Waongo <i>et al.</i> (2015)
2014	26	Asafu-Adjaye (2014); Bayala <i>et al.</i> (2014); Busby <i>et al.</i> (2014); Chaney <i>et al.</i> (2014) agriculture, and infrastructure is necessary to adequately prepare and adapt to future change. This is a challenge in data-sparse regions such as sub-Saharan Africa, where a lack of high-density and temporally consistent long-term <i>in situ</i> measurements complicates the analysis. To address this, a temporally homogenous and high-temporal- and high-spatial-resolution meteorological dataset is developed over sub-Saharan Africa (5°S–25°N; Corbeels <i>et al.</i> (2014); Coulibaly <i>et al.</i> (2014); D'haen <i>et al.</i> (2014); Folberth <i>et al.</i> (2014); Johnson and Brown (2014); Kima <i>et al.</i> (2014); Lambin <i>et al.</i> (2014); Lodoun <i>et al.</i> (2014); López-Carr <i>et al.</i> (2014); Naumann <i>et al.</i> (2014); Rasmussen <i>et al.</i> (2014); Seo (2014); Sheffield <i>et al.</i> (2014); Shi and Tao (2014); Sultan <i>et al.</i> (2014); Thornton and Herrero (2014); vom Brocke <i>et al.</i> (2014); von Uexkull (2014); Waongo <i>et al.</i> (2014); Ward <i>et al.</i> (2014); Wood <i>et al.</i> (2014); Zampaligré <i>et al.</i> (2014)
2013	14	Calzadilla <i>et al.</i> (2013); Faramarzi <i>et al.</i> (2013); Heubes <i>et al.</i> (2013); Liu <i>et al.</i> (2013); Lobell <i>et al.</i> (2013); Mahe <i>et al.</i> (2013); Ramirez-Villegas <i>et al.</i> (2013); Sultan <i>et al.</i> (2013); Traore and Owiyi (2013); Vrieling <i>et al.</i> (2013); Waha <i>et al.</i> (2013a); Waha <i>et al.</i> (2013b); Yang <i>et al.</i> (2013); Zorom <i>et al.</i> (2013)
2012	10	Brockhaus <i>et al.</i> (2012); Haussmann <i>et al.</i> (2012); Jarvis <i>et al.</i> (2012); Jung <i>et al.</i> (2012); Kniveton <i>et al.</i> (2012); Lahmar <i>et al.</i> (2012); Luedeling and Neufeldt (2012); Rosenthal and Ort (2012); Rudi <i>et al.</i> (2012); Tittonell <i>et al.</i> (2012)
2011	10	Arthur and Baidoo (2011); Belem <i>et al.</i> (2011); Bhaduri <i>et al.</i> (2011); Kalame <i>et al.</i> (2011); Mertz (2011); Paeth (2011); Proud and Rasmussen (2011); Sissoko <i>et al.</i> (2011); Thornton <i>et al.</i> (2011); Traoré <i>et al.</i> (2011)
2010	5	Garrity <i>et al.</i> (2010); Mertz <i>et al.</i> (2010); Nielsen and Reenberg (2010); Schlenker and Lobell (2010); Zorom <i>et al.</i> (2010)
2009	5	Barbier <i>et al.</i> (2009); Jones and Thornton (2009); Lay <i>et al.</i> (2009); Ramin and McMichael (2009); Seo <i>et al.</i> (2009)
2008	6	Barrios <i>et al.</i> (2008); Cooper <i>et al.</i> (2008); Lobell <i>et al.</i> (2008); Mishra <i>et al.</i> (2008); Vrieling <i>et al.</i> (2008); West <i>et al.</i> (2008)
2007	4	Bostick <i>et al.</i> (2007); Hendrix and Glaser (2007); Perez <i>et al.</i> (2007); Wittig <i>et al.</i> (2007)
2005	2	Haile (2005); Wang (2005)
2002	4	Groten and Ocatre (2002); Ingram <i>et al.</i> (2002); Ringius (2002); Taylor <i>et al.</i> (2002)
2001	1	Roncoli <i>et al.</i> (2001)

Table 3: Topics addressed in the systematic review

Item	Elements analysed in the selected documents
Bibliographical metrics	Subject areas, sources/journals, authors, affiliation institutions, affiliation countries, study countries
Topical focus of research on climate change and agriculture in BF	Agriculture subsectors: crop production, animal production and fisheries Changing climate in BF (e.g. trends in air temperature and rainfall, droughts, extreme weather events) Agriculture and climate change mitigation (e.g. GHG emissions from agriculture, soil carbon sequestration, conservation agriculture) Impacts of climate change on Burkinabe agriculture (e.g. impacts on agricultural production and yields, crop suitability, natural resources, food security, pests and diseases, conflicts) Adaptation of Burkinabe agriculture to climate change (e.g. crop diversification, intensification, irrigation, livelihoods diversification, migration)

Table 4: Bibliographical metrics of the literature on climate change and agriculture in BF: top-ten journals, research areas, authors, affiliations and countries

Journals (a)	Research areas (b)	Authors (c)	Affiliations (d)	Countries (e)
Climatic Change (10)	Environmental Sciences - Ecology (97)	Sultan, B. (9)	CIRAD (17)	USA (66)
Environmental Research Letters (10)	Meteorology - Atmospheric Sciences (61)	Mertz, O. (8)	University of Copenhagen (15)	Burkina Faso (47)
Agricultural Systems (8)	Agriculture (38)	Thornton, P. K. (7)	Helmholtz Association (13)	Germany (45)
Global Environmental Change (7)	Science Technology (22)	Baron, C. (6)	<i>Institut de Recherche pour le Développement</i> – IRD (13)	France (31)
Regional Environmental Change (6)	Business Economics (15)	Herrero, M. (6)	ILRI (13)	England (28)
Climate (5)	Geology (15)	Kunstmann, H. (6)	Wageningen University Research (13)	Kenya (28)
Global and Planetary Change (5)	Geography (14)	Lobell, D. B. (6)	International Food Policy Research Institute – IFPRI (12)	Netherlands (22)
Journal of Climate (5)	Water Resources (11)	Yang, H. (6)	Columbia University (11)	Australia (18)
Nature Climate Change (5)	Development Studies (9)	Barbier, B.; Bayala, J.; Nielsen, J.O.;	Karlsruhe Institute of Technology (11)	Denmark (17)
PLoS One (5)	Food Science Technology (7)	Rasmussen, K.; Rasmussen, L.V. (5)	CNRS, Commonwealth Scientific Industrial Research Organisation (CSIRO), ICRISAT, Sorbonne Université, University of Bonn, ICRAF (10)	Mali (16)

Legend: Figures in brackets refer to the number of documents by journal (a), research area (b), author (c), affiliation institution (d), or affiliation country (e)

agriculture in BF and beyond (e.g. West Africa, Sahel). Indeed, the average yearly output of articles in the considered period (2001-2020) is about 11; it ranges from one in 2001 to a maximum of 30 papers published in 2017 and 2018.

As for journals and sources, the highest number of papers was published in *Climatic Change* (10 articles), *Environmental Research Letters* (10 articles), *Agricultural Systems* (8 articles), and *Global Environmental Change* (7 articles). Nevertheless, the results of the research on climate change and agriculture in BF were published in 116 sources and journals. Most of the selected documents are linked to the research areas of environmental sciences – ecology (97 documents), meteorology – atmospheric sciences (61 documents) and agriculture (38 documents). Nonetheless, the selected documents can be categorized in 35 research areas (e.g. business economics, geography, development studies, computer science, engineering, mathematics, geochemistry, geophysics), which might indicate the ‘multidisciplinarity’ of the research field.

The most prominent scholars in the research field are Benjamin Sultan (9 documents), Ole Mertz (8 documents) and Philip K.

Thornton (7 documents). Meanwhile, the analysis of author affiliations and countries shows that most of the research on climate change and agriculture in BF was carried out by researchers based in developed countries in North America (viz. USA, Canada), Europe (e.g. Germany, France, England, Netherlands, Denmark, Italy, Switzerland, Spain, Sweden, Belgium) and Oceania (viz. Australia). Collaborations of Burkinabe scientists with researchers from developed countries are needed and should be encouraged. Moreover, it is worth mentioning that many scientists based in Africa, especially West Africa (e.g. Kenya, Mali, Niger, Nigeria, Ghana, South Africa, Ivory Coast, Senegal, Zimbabwe, Benin), are active in the research field. This might be explained, among others, by the fact that many international organisations (e.g. CGIAR) have branches in Africa (e.g. International Livestock Research Institute – ILRI, International Crops Research Institute for the Semi-Arid Tropics – ICRISAT, World Agroforestry – ICRAF). Moreover, more and more studies are performed by researchers based in China. The most prominent institutions, as per author affiliations, are the French Agricultural Research Centre for International Development – CIRAD (17 documents) and the University of Copenhagen (15 documents). Active Burkinabe

research centres and institutions include the *Centre National de la Recherche Scientifique* (CNRS) and the University of Ouagadougou.

Most of the selected documents (45.2% i.e. 98 documents out of 217) deal with the whole Sub-Saharan Africa (see, Supplementary Material – Appendix 1). These are followed by some multi-country – e.g. BF with a neighbouring country such as Benin (Callo-Concha, 2018, 2016) or Ghana (Boansi *et al.*, 2017, 2019) – and regional (West Africa, Sahel) studies (31.8% i.e. 69 out of 217). Less than a quarter of the selected studies (23.0% i.e. 50 out of 217) address the relationships between agriculture and climate change in Burkina Faso or even single regions in the country e.g. north (Hänke *et al.*, 2016; Kima *et al.*, 2014; Rigolot *et al.*, 2017), south (Borona *et al.*, 2016; Dimobe *et al.*, 2018), south-west (Fonta *et al.*, 2015; Sanfo *et al.*, 2017) and south-east (Mande *et al.*, 2015).

Agriculture Subsectors: Crop Production, Animal Production and Fisheries

Most of the selected papers deal with crop production, while animal production (7 documents out of 217) and, especially, fisheries (1 document) are overlooked (see, Supplementary Material – Appendix 2). As for crop production (82 documents out of 217), the majority of articles addresses climate change mitigation and/or adaptation in relation to staple crops – such as cassava (Egbebiyi, Crespo, *et al.*, 2019; Egbebiyi, Lennard, *et al.*, 2019; Jarvis *et al.*, 2012; Rosenthal & Ort, 2012), maize (Kamali *et al.*, 2018, 2019; Nelimor *et al.*, 2019; Parkes *et al.*, 2018; Ugbaje *et al.*, 2019), millet (Egbebiyi, Crespo, *et al.*, 2019; Faye *et al.*, 2018; Pironon *et al.*, 2019; Sultan *et al.*, 2013; Sultan, Defrance, *et al.*, 2019), rice (Kima *et al.*, 2014; van Oort & Zwart, 2018; Zhang *et al.*, 2019), sesame (Lokonon *et al.*, 2019), sorghum (Akinseye *et al.*, 2020; Hadebe *et al.*, 2017; Sultan *et al.*, 2014; Sultan, Defrance, *et al.*, 2019; vom Brocke *et al.*, 2014), and yam (Pironon *et al.*, 2019) – or cash crops such as cotton (Bostick *et al.*, 2007; Ingram *et al.*, 2002; Zorom *et al.*, 2010), mango (Egbebiyi, Crespo, *et al.*, 2019), sugarcane (Lokonon *et al.*, 2019) and groundnuts (Hoffman *et al.*, 2018; Schlenker & Lobell, 2010). Most of the selected documents deal with ‘rural agriculture’, while urban and peri-urban agriculture (UPA) is marginal (Nkrumah, 2019). Many papers analyse the impacts of climate change on mixed systems (96 documents out of 217) such as agro-pastoral systems. This is particularly the case of documents that address climate change adaptation by rural and agricultural households. Further documents (31 documents out of 217) deal with both agriculture and forestry (e.g. agroforestry). This category also includes articles that analyse changes in land use in agricultural areas due to changing climate in BF or West Africa and Sahel at large.

Topics Addressed in the Research Field

Changing climate in BF: trends in air temperature and rainfall

The analysis of changes in climate is based on modern knowledge (cf. conventional science) and/or traditional/indigenous

knowledge. The former consists in retrospective studies, which analyse past changes in temperatures and/or rainfall in BF, or prospective studies that provide projections of temperatures and/or rainfall based on methods such as modelling or scenarios. The latter approach encompasses analysing the perceptions and opinions of the concerned actors (e.g. farmers, pastoralists) about the changing climate in the country.

Sultan and Gaetani (2016) suggest that “*West Africa is nowadays experiencing a rapid climate change, characterized by a widespread warming, a recovery of the monsoonal precipitation, and an increase in the occurrence of climate extremes*”. As for warming, Sultan *et al.* (2019) found that “*the last simulated decade, 2000-2009, is approximately 1 degrees C warmer in West Africa in the ensemble accounting for human influences on climate, with more frequent heat and rainfall extremes*”. Referring to West Africa, Sarr (2012) highlights that observations already indicate an average increase in temperature of 0.2-0.8°C since the end of the 1970s (ECOWAS-SWAC *et al.*, 2008); when projected, this increases to between 3.0 and 4.0°C between 1980/1999 and 2080/2099 (IPCC, 2007). Sultan *et al.* (2014) put that the “*subset of bias-corrected climate models projects a mean warming of +2.8 degrees C in the decades of 2031-2060 compared to a baseline of 1961-1990*” in West Africa. Likewise, Olusegun *et al.* (2018) argue that “*Widespread warming (1-3 degrees C) and drying (1-2 mm/day) is projected in the near future across most parts of West Africa all year round*”. Kima *et al.* (2015) show that “*the annual minimum and maximum temperatures showed a statistically significant upward trend, with a rate of change of 0.20 degrees C and 0.27 degrees C per decade*” in BF over the period 1980-2012.

As for precipitation and rainfall, studies highlight their increasing variability across the region (Sidibe *et al.*, 2019). Nevertheless, Klutse *et al.* (2018) point out that the “*enhanced warming results in a reduction in mean rainfall across the region*” in West Africa. Contrariwise, Bicher and Diedhiou (2018) found that “*the recent increase in precipitation results principally from an increase in the number of wet days (+10 d compared to the normal) over the entire West African Sahel band, along with an increase in the precipitation intensity over the central part of the West African Sahel (+ 3 mm d(-1))*” (p. 155). In their analysis of the long-term annual trends of rainfall from 1980 to 2012 in BF, Kima *et al.* (2015) put that “*within the period of study, the annual rainfall showed an upward trend, with high inter-annual variability and 818.9 mm of mean annual rainfall*”. It seems that the impacts of climate change on rainfall will vary across West Africa; Sultan *et al.* (2014) predict “*a robust change in rainfall in West Africa with less rain in the Western part of the Sahel (Senegal, South-West Mali) and more rain in Central Sahel (Burkina Faso, South-West Niger)*” by 2060.

One of the indicators of the changing climate in West Africa and Sahel is the increase of the frequency of extreme weather events such as droughts (Chaney *et al.*, 2014; Haile, 2005; Klutse *et al.*, 2018; Oguntunde *et al.*, 2017; Traore & Owiyo, 2013) and intensive rainfalls (Berthou *et al.*, 2019; Bichet & Diedhiou, 2018; Klutse *et al.*, 2018). Climatic fluctuations also impact river catchments and streamflow (Andam-Akorful *et al.*, 2017; Bhaduri *et al.*, 2011; Mahe *et al.*, 2013; Oguntunde *et al.*, 2017; Sidibe *et al.*, 2019; Sossa *et al.*, 2017) with implications for water

resources availability as well as flood frequencies (Haile, 2005; Sidibe *et al.*, 2019; Sossa *et al.*, 2017; Sylla *et al.*, 2015).

Other studies focus on the perception of climate change (Boansi *et al.*, 2017, 2019; Callo-Concha, 2018; Fonta *et al.*, 2015; Zampaligré *et al.*, 2014). Boansi *et al.* (2019) argue that “Based on farmers’ perception, it is found that drought, low rainfall, intense precipitation, flooding, erratic rainfall pattern, extremely high temperatures, delayed rains, and early cessation of rains are the major threats farmers face” (p. 355). However, referring to farmer perceptions on climate change in West Africa (Benin and Burkina Faso), Callo-Concha (2018) suggest that “responses regarding climate change perception and adaptation are frequently subjective, conjectural and inconsistent”, which might imply that some caution is needed when dealing with them.

Some scholars report a phenomenon of ‘greening’ (Epule *et al.*, 2014) or ‘regreening’ (Stith *et al.*, 2016) in the Sahel region and link it to climate change. For instance, Epule *et al.* (2014) hypothesize that “the increase in CO₂ might be responsible for the increase in greening and rainfall observed. This can be explained by an increased aerial fertilization effect of CO₂ that triggers plant productivity and water management efficiency through reduced transpiration”. Other authors point out a slight rainfall recovery over the Sahel which is concomitant with a climate warming in the region (Salack *et al.*, 2016). Global warming also triggers hybrid rainy seasons in the Sahel, which represents a real challenge for rain-fed farming systems (Salack *et al.*, 2016).

In this context of sometimes contradictory data, some scholars raised concerns regarding the accuracy and reliability of projections based on climate models (Berthou *et al.*, 2019; Dale *et al.*, 2017; Guan *et al.*, 2017; Paeth, 2011; Ramirez-Villegas & Challinor, 2012). For instance, Paeth (2011) put that “climate models tend to produce systematic errors, especially, in terms of rainfall and cloud processes, which are usually approximated by physical parameterizations” (p. 1321). Likewise, Ramirez-Villegas and Challinor (2012) argue that “Climate models were found inadequate for field-scale agricultural studies in West Africa and South Asia, as their ability to represent mean climates and climate variability was limited” (p. 26).

Climate change mitigation and adaptation

Most of the analysed documents deal with the adaptation of the Burkinabe agriculture to climate change (Table 5). However, many articles address simultaneously mitigation of and adaptation to climate change in agriculture. For instance, climate-smart agriculture (Abegunde *et al.*, 2019; Makate, 2019; Prestele & Verburg, 2020) does not only allow reducing GHG emissions but also making agriculture more climate-resilient. The analysis of adaptation and mitigation options is often preceded by referring to the impacts of climate change on agriculture in the country or the wider region (e.g. West Africa, Sahel, SSA). The literature shows that some initiatives and projects even seek the ‘triple-wins’ of development, adaptation and mitigation (Suckall *et al.*, 2015).

Agriculture and climate change mitigation

Some of the selected papers deal with the assessment of GHG emissions from agriculture as well as strategies and options to reduce them. Other papers analyse how agriculture can be used to sequester carbon thus reducing the CO₂ concentrations in the atmosphere. Referring to GHG emissions in SSA, Kim *et al.* (2016) put that “Carbon dioxide (CO₂) emissions were by far the largest contributor to GHG emissions and global warming potential (GWP) in SSA” (p. 4789) thus exceeding methane (CH₄) and nitrous oxide (N₂O) emissions. Emissions are affected, among others, by crop residues and manure management, and fertilisation (Kim *et al.*, 2016).

The management of soil organic matter is central in the responses to climate change. In this regard, Kamoni and Gicheru (2015) argue that “Increasing soil organic matter content can both improve soil fertility and reduce the impact of drought, improving adaptive capacity, making agriculture less vulnerable to climate change, while also sequestering carbon” (p. 307). Referring to conservation agriculture (CA), Powlson *et al.* (2016) put that “It is also claimed to mitigate climate change through soil carbon sequestration” (p. 164) and argue that “the mitigation potential, and other benefits, from crop diversification are frequently overlooked when considering CA and warrant greater attention” (p. 164). Indeed, Kamoni and Gicheru (2015) pinpoint that “Sustainable land management practices enhance carbon sequestration and sustain agricultural productivity, thus mitigating against climate change” (p. 307). Agroforestry (Luedeling & Neufeldt, 2012; Mutuo *et al.*, 2005; Olusegun *et al.*, 2018) is also considered as a means to increase carbon sequestration and reduce GHG emissions. Mutuo *et al.* (2005) suggest that “Evidence is emerging that agroforestry systems are promising management practices to increase aboveground and soil C stocks and reduce soil degradation, as well as to mitigate greenhouse gas emissions” (p. 43). However, Dimobe *et al.* (2018) underline that the success of carbon sequestration projects, including those involving agro-forestry, lies in the “involvement of local populations in the selection of woody species [...] and information about the potential of these species to store carbon”. Moreover, there are some doubts about whether carbon sequestration markets (cf. Clean Development Mechanism - CDM) benefit African low-income producers; for instance, Perez *et al.* (2007) argue that “while C payments may contribute to increasing rural incomes and promoting productivity enhancement practices, they may also expose resource users to additional social tensions and institutional risks” (p. 2). In this context, Ringius (2002) highlight the need for more studies on opportunities and challenges of soil carbon sequestration in Africa.

Different strategies are suggested to mitigate climate change. These include some controversial ones such as the use of genetically modified crops (GMCs). Indeed, Quintero and Cohen (2019) highlight that BF is one of countries that “could be the best contributors to the mitigation of the climate change by the reduction of their CO₂ emission levels through GMCs” (p. 641). Furthermore, intensification (in crop production, animal production and mixed crop-livestock systems) is presented as one of the strategies to combine food security and climate change

Table 5: Examples of documents addressing mitigation of and/or adaptation to climate change in the analysed scholarly literature

Mitigation vs. Adaptation	References
Mitigation	Arthur and Baidoo (2011); Belem <i>et al.</i> (2011); Bennetzen <i>et al.</i> (2016); Bostick <i>et al.</i> (2007); Dimobe <i>et al.</i> (2018); Doelman <i>et al.</i> (2018); Egbendewe (2018); Henderson <i>et al.</i> (2017); Hendrix and Glaser (2007); Kamoni and Gicheru (2015); Luedeling and Neufeldt (2012); Ogundari <i>et al.</i> (2017); Perez <i>et al.</i> (2007); Quintero and Cohen (2019); Ringius (2002); Torquebiau (2017); van Loon <i>et al.</i> (2019)
Adaptation	Abidoye and Odusola (2015); Amjath-Babu <i>et al.</i> (2016); Asafu-Adjaye (2014); Asare-Kyei <i>et al.</i> (2017); Barbier <i>et al.</i> (2009); Belesova <i>et al.</i> (2019); Boansi <i>et al.</i> (2017); Bodin <i>et al.</i> (2016); Brockhaus <i>et al.</i> (2012); Bryan <i>et al.</i> (2018); Buhaug <i>et al.</i> (2015); Bunclark <i>et al.</i> (2018); Busby <i>et al.</i> (2014); Callo-Concha (2016); Callo-Concha (2018); Calzadilla <i>et al.</i> (2013); Chen <i>et al.</i> (2018); Choptiany <i>et al.</i> (2017); Cooper <i>et al.</i> (2008); D'haen <i>et al.</i> (2014); Di Leo <i>et al.</i> (2016); Dixon and Stringer (2015); Douxchamps <i>et al.</i> (2016); Fonta <i>et al.</i> (2015); Gahi <i>et al.</i> (2015); Garcia de Jalon <i>et al.</i> (2018); Gray and Wise (2016); Guan <i>et al.</i> (2017); Haile (2005); Haussmann <i>et al.</i> (2012); Ingram <i>et al.</i> (2002); Jarvis <i>et al.</i> (2012); Johnson and Brown (2014); Jones and Thornton (2009); Kalame <i>et al.</i> (2011); Kima <i>et al.</i> (2014); Kima <i>et al.</i> (2015); Kniveton <i>et al.</i> (2012); Lay <i>et al.</i> (2009); Lebel <i>et al.</i> (2015); Lobell <i>et al.</i> (2008); López-Carr <i>et al.</i> (2014); McPeak (2017); Mertz (2011); Mertz <i>et al.</i> (2010); Mertz <i>et al.</i> (2016); Naumann <i>et al.</i> (2014); Palazzo <i>et al.</i> (2017); Parkes <i>et al.</i> (2018); Pironon <i>et al.</i> (2019); Ramin and McMichael (2009); Rasmussen (2018); Rasmussen <i>et al.</i> (2014); Rigolot <i>et al.</i> (2017); Rippke <i>et al.</i> (2016); Roncoli <i>et al.</i> (2001); Rosenthal and Ort (2012); Salack <i>et al.</i> (2015); Sanfo <i>et al.</i> (2017); Schlenker and Lobell (2010); Seo <i>et al.</i> (2009); Serdeczny <i>et al.</i> (2017); Sheffield <i>et al.</i> (2014); Sidibé <i>et al.</i> (2018); Siebert (2016); Sissoko <i>et al.</i> (2011); Sonwa <i>et al.</i> (2017); Sorgho <i>et al.</i> (2016); Tankari (2020); Tesfaye <i>et al.</i> (2015); Thornton and Herrero (2014); Thornton and Herrero (2015); Thornton <i>et al.</i> (2011); Traoré <i>et al.</i> (2011); van Oort and Zwart (2018); van Wesenbeeck <i>et al.</i> (2016); vom Brocke <i>et al.</i> (2014); von Uexkull (2014); Waha <i>et al.</i> (2013); Waha <i>et al.</i> (2016); Waongo <i>et al.</i> (2015); West <i>et al.</i> (2008); Wood <i>et al.</i> (2014); Zampaligré and Fuchs (2019); Zampaligré <i>et al.</i> (2014); Zidouemba (2017); Zorom <i>et al.</i> (2010); Zorom <i>et al.</i> (2013)
Mitigation and adaptation	Bayala <i>et al.</i> (2014); Corbeels <i>et al.</i> (2014); Coulibaly <i>et al.</i> (2014); Descheemaeker <i>et al.</i> (2016); Fanzo <i>et al.</i> (2018); Garrity <i>et al.</i> (2010); Hasegawa <i>et al.</i> (2018); Henderson <i>et al.</i> (2016); Lahmar <i>et al.</i> (2012); Lobell <i>et al.</i> (2013); Prestele and Verburg (2020); Richardson <i>et al.</i> (2018); Steward <i>et al.</i> (2018); Tittonell <i>et al.</i> (2012)

mitigation (Ayantunde *et al.*, 2020; Descheemaeker *et al.*, 2016; van Loon *et al.*, 2019). Nevertheless, referring to cereal cropping in 10 countries in SSA (i.e. Burkina Faso, Ethiopia, Ghana, Kenya, Mali, Niger, Nigeria, Tanzania, Uganda and Zambia), van Loon *et al.* (2019) conclude that “*intensification scenarios are clearly superior to expansion scenarios in terms of climate change mitigation*” (p. 3720) but point out that “*irrespective of intensification or extensification, GHG emissions of the 10 countries jointly are at least 50% higher in 2050 than in 2015. Intensification will come, depending on the nutrient use efficiency achieved, with large increases in nutrient inputs and associated GHG emissions*” (p. 3720). Furthermore, cropland intensification threatens biodiversity in Sub-Saharan Africa (Zabel *et al.*, 2019). This is one of the environmental costs of mitigation, but also economic costs of abating GHG emissions (Henderson *et al.*, 2017; Lobell *et al.*, 2013; Ringius, 2002) as well as social ones (e.g. food security) should be considered for an accurate evaluation of mitigation strategies and options in BF and SSA at large.

Impacts of climate change on Burkinabe agriculture

Climate change can have different and far-reaching impacts on agriculture and rural populations in SSA. Indeed, Zougmore *et al.* (2018) suggest that “[...] *without appropriate interventions, climate change and variability will affect agricultural yields, food security and add to the presently unacceptable levels of poverty in sub-Saharan Africa*”. Some papers analyse the impacts of climate change on agricultural production and yields (Lokonon *et al.*, 2019; Serpantié *et al.*, 2019; Sultan, Defrance, *et al.*, 2019). Analyses regard different crops such as cassava (Egbebiyi, Crespo, *et al.*, 2019; Egbebiyi, Lennard, *et al.*, 2019; Jarvis *et al.*, 2012; Rosenthal & Ort, 2012), maize (Kamali *et al.*, 2018, 2019; Nelimor *et al.*, 2019; Parkes *et al.*, 2018; Ugbaje *et al.*, 2019), mango (Egbebiyi, Crespo, *et al.*, 2019), millet (Egbebiyi, Crespo, *et al.*, 2019; Faye *et al.*, 2018;

Pironon *et al.*, 2019; Sultan *et al.*, 2013; Sultan, Defrance, *et al.*, 2019) and sorghum (Akinseye *et al.*, 2020; Hadebe *et al.*, 2017; Sultan *et al.*, 2014; Sultan, Defrance, *et al.*, 2019; vom Brocke *et al.*, 2014). Sultan and Gaetani (2016) highlight that “*a robust evidence of yield loss in West Africa emerges. This yield loss is mainly driven by increased mean temperature while potential wetter or drier conditions as well as elevated CO₂ concentrations can modulate this effect*”. Lokonon *et al.* (2019) show that “*paddy rice, oilseeds, sugarcane, cocoa, coffee, and sesame production could experience a decline under both moderate and harsh climate conditions*” in the Economic Community of West African States (ECOWAS). Referring to about 1 degree C warming in West Africa in the decade 2000–2009, Sultan *et al.* (2019) posit that “*These altered climate conditions have led to regional average yield reductions of 10-20% for millet and 5-15% for sorghum*”. Production loss also implies the loss of income for farmers and revenues for countries. Sultan *et al.* (2019) found that “*the average annual production losses across West Africa in 2000-2009 associated with historical climate change, relative to a non-warming counterfactual condition (that is, pre-industrial climate), accounted for 2.33-4.02 billion USD for millet and 0.73-2.17 billion USD for sorghum*”. However, other scholars, argue that the so-called ‘carbon fertilisation’ may offset the impact of global warming on crop yields. Indeed, Roudier *et al.* (2011) put that “*results highlight the pivotal role that the carbon fertilization effect may have on the sign and amplitude of change in crop yields*” (p. 1073).

Referring to West Africa, Sarr (2012) points out that “*Of greater concern, however, is the late onset, early cessation dates of rainfall and reduction of length of growing period (LGP) which are now locally negatively impacting agriculture in the region. Furthermore, projections indicate a 20% reduction of LGP in 2050*” (p. 108). Climate change is also expected to affect crop suitability in BF as well as West Africa at large (Egbebiyi,

Crespo, *et al.*, 2019; Egbebiyi, Lennard, *et al.*, 2019; Ugbaje *et al.*, 2019). Referring to the three agro-ecological zones of West Africa (viz. Guinea, Savanna and Sahel), Egbebiyi *et al.* (2019) point out that “warming is projected to constrain crop growth suitability for cassava and pineapple in the Guinea zone”. Also the suitability for other crops (e.g. maize, mango, pearl millet) will be affected by the changing climate in the region. Indeed, Ugbaje *et al.* (2019) show that, regardless of the trajectory of future rainfall projection, temperature projection will decrease suitability for rain-fed maize in West African region by 2080.

Another topic that is related to the impacts of climate change on agricultural production is food security. Indeed, many scholars (Fanzo *et al.*, 2018; Hadebe *et al.*, 2017; Haile, 2005; Hasegawa *et al.*, 2018; Niles & Brown, 2017; Richardson *et al.*, 2018; Rigolot *et al.*, 2017; Sultan, Defrance, *et al.*, 2019; Tesfaye *et al.*, 2015) highlight the detrimental effects of climate change on the food security of the population in BF and Sahel at large. Most of the analysed papers focus on the damages of climate change to agriculture thus reducing food availability; however, Hasegawa *et al.* (2018) highlight that also stringent climate change mitigation measures can increase food insecurity risk in Sub-Saharan Africa. Therefore, one pressing challenge is how to reconcile socio-economic development (including the achievement of food security) and environmental conservation (including climate change mitigation) in BF and Sub-Saharan Africa as a whole (Rudi *et al.*, 2012).

The impacts of food insecurity and malnutrition caused by production decrease due to global warming might be particularly severe among vulnerable groups such as children (Belesova *et al.*, 2019; Sorgho *et al.*, 2016) and women (Bryan *et al.*, 2018; Huyer, 2016). Indeed, Belesova *et al.* (2019) show that low annual crop yields in the scenario of 1.5 degrees C warmer climate in 2100 would increase child mortality in a subsistence farming population of Nouna district (Kossi Province, western Burkina Faso). Moreover, evidence shows that the impacts of climate change are higher on smallholders (García de Jalón *et al.*, 2018; Henderson *et al.*, 2016; Waha *et al.*, 2016; Williams *et al.*, 2018; Wood *et al.*, 2014). In this regard, Williams *et al.* (2018) put that “The impacts of changing climate on agriculture have consequences on livelihoods and food security. Smallholder farmers, who have heterogeneous farming systems and limited resources, compounded with multiple risks, are greatly affected”.

Climate change is also expected to affect the incidence of pests and diseases (Botha *et al.*, 2020; Jarvis *et al.*, 2012; Sileshi *et al.*, 2019; Wilcox *et al.*, 2019) with increasing damages on crops and animals. Botha *et al.* (2020) suggest that “[...] median temperature increases are associated with increased pest pressure and changes in migratory patterns. These factors will result in significantly more pest invasions and an increased need for innovative insect management practices”. Likewise, Jarvis *et al.* (2012) show that the geographic distribution as well as the severity of cassava pests and diseases (e.g. whitefly, cassava mosaic disease, cassava mealybug, brown streak disease) are projected to change.

Another impact of climate change is the increase in conflicts (Buhaug *et al.*, 2015; Döring, 2020; Hendrix & Glaser, 2007; Jun, 2017; Mertz *et al.*, 2016; von Uexkull, 2014; Witmer *et al.*, 2017) mainly on natural resources such as water (both surface water and groundwater) and pastures/rangelands. For instance, Jun (2017) found that “between 1970 and 2012 in sub-Saharan Africa, a high temperature during maize growing season reduced the crop’s yield, which in turn increased the incidence of civil conflict and [...] future expected warming is expected to increase civil conflict incidence by 33% in the period 2031-2050, and by 100% in the period 2081-3010, compared to levels between 1981 and 2000” (p. 183). Meanwhile, von Uexkull *et al.* (2016) conclude that “for agriculturally dependent groups as well as politically excluded groups in very poor countries, a local drought is found to increase the likelihood of sustained violence” (p. 12391).

While estimates of climate change impacts rely on the use of different models, climate modelling is more and more criticised (Ackerman & Munitz, 2016), which means that some caution is needed when using these generated data. Indeed, it should be pointed out that the assessments of the impacts of climate change on agriculture are subject to considerable model uncertainties and deficiencies (Druyan, 2011; Müller, 2013; Muller *et al.*, 2011). In this respect, Müller (2013) assume that “There are multiple reasons for differences in projections, including uncertainties in greenhouse gas emissions and patterns of climate change; assumptions on future management, aggregation, and spatial extent; and methodological differences” (p. 395).

Adaptation of Burkinabe agriculture to climate change

The literature shows that BF is highly vulnerable to climate change (Busby *et al.*, 2014). Indeed, Busby *et al.* (2014) identify the country as a hotspot of climate change vulnerability in Africa and the situation is expected to worsen in the future; Indeed, they put that “For the late 20th century, this mapping process reveals the most vulnerable areas are concentrated in Chad, the Democratic Republic of the Congo, Niger, Somalia, Sudan, and South Sudan, with pockets in Burkina Faso, Ethiopia, Guinea, Mauritania, and Sierra Leone. The mid 21st century projection shows more extensive vulnerability throughout the Sahel, including Burkina Faso, Chad, Mali, northern Nigeria, Niger, and across Sudan” (p. 717). This makes vital the adoption of climate change adaptation measures.

Most of the selected articles deal with climate change adaptation in crop production while animal production and agro-forestry are often overlooked. This is corroborated by the findings of Gautier *et al.* (2016) who put that “The literature on responses to drought focuses on agricultural and individual responses, while diversification, migration, and tree-based or livestock-based responses are less frequently addressed” (p. 666). Some papers focus on the resilience and adaptation of smallholders to climate change (García de Jalón *et al.*, 2018; Henderson *et al.*, 2016; Waha *et al.*, 2016; Williams *et al.*, 2018; Wood *et al.*, 2014) while others deal with pastoralists or agro-pastoralists (Choptiany *et al.*, 2017; Rasmussen *et al.*, 2014, 2015; Zampaligré *et al.*, 2014). Other papers have a more specific focus such as women (Bryan

et al., 2018; Huyer, 2016). As for climate change adaptation in West African fisheries, Katikiro and Macusi (2012) suggest that “Diversifying fish sources may enable the region’s rural households to cope and adapt to climate change impacts” (p. 83).

Akinseye *et al.* (2020) argue that “Climate variability and change will have far reaching consequences for smallholder farmers in sub-Saharan Africa, the majority of whom depend on agriculture for their livelihoods”. Azzari and Signorelli (2020) show that there is a strong correlation between climatic conditions, and climate change (cf. rain/flood and heat shocks), and household welfare/poverty in Sub-Saharan Africa. Gautier *et al.* (2016) put that “in West Africa, climate variations and droughts have always affected livelihoods but have also triggered adaptation strategies” (p. 666). Indeed, different strategies are adopted by agricultural and rural households to adapt to climate change. These strategies range from changes in the cropping systems, diversification of livelihoods to migration. In this context, Sissoko *et al.* (2011) put that “To cope with the difficult climatic situation, farm households have developed a range of strategies including selling of animals and on-farm diversification or specialization” (p. 119). Roncoli *et al.* (2001) argue that “Livelihood diversification, encompassing migration, non-farm work and social support networks, in addition to livestock production, is shown to be a critical dimension of adaptation” (p. 119). Muchuru and Nhamo (2019) enumerate among the categories of adaptation measures in the African crop sector promoted by governments “conservation agriculture; water, irrigation and flood management; crop diversification; inputs and subsidies; disease and pest management; and weather-based index insurance”. Partey *et al.* (2018) found “agroforestry (farmer-managed natural regenerations), soil and water conservation technologies (zai, half-moon, tie/contour ridges, conservation agriculture) and [...] climate information services as highly valued promising options for climate change adaptation and risk management in West Africa” (p. 285). The concept of climate-smart agriculture is central in adaptation strategies and measures. In this context, Zougmore *et al.* (2018) put that “the past decades have seen the development and promotion of climate-smart agriculture innovations such as the use of high yielding drought tolerant crop varieties, climate information services, agricultural insurance, agroforestry, water harvesting techniques, integrated soil fertility management practices, etc.”.

As for changes in the cropping system, Boansi *et al.* (2019) argue that “To moderate harm from anticipated weather extremes, farmers need to adjust their cropping calendar, adopt appropriate crop varieties, and implement soil and water management practices” (p. 355). There are broadly two distinct strategies that consists in either keeping the same crop(s) while changing the cropping cycle and crop management, or introducing new crops or cultivars that are more adapted to climate change. Referring to the literature on climate change in West Africa, Sultan and Gaetani (2016) argue that “Potential for adaptation is illustrated for major crops in West Africa through a selection of studies based on process-based crop models to adjust cropping systems (change in varieties, sowing dates and density, irrigation, fertilizer management) to future climate”. Changes in the cropping system encompass varying the sowing/planting time (Egbebiyi, Crespo, *et al.*, 2019; Egbebiyi, Lennard, *et al.*, 2019;

Waha, Müller, Bondeau, *et al.*, 2013). However, Guan *et al.* (2017) assess five adaptation options for sorghum “(i) late sowing, (ii) intensification of seeding density and fertilizer use, (iii) increasing cultivars’ thermal time requirement, (iv) water harvesting, and (v) increasing resilience to heat stress during the flowering period” (p. 291) and point out that they are not effective in reducing the impacts of climate change on sorghum production in West Africa. Referring to farmers in eastern Ghana and south-western BF, Boansi *et al.* (2019) argue that “Due to recent changes in onset of rains and length of the rainy season, some farmers have either resorted to early planting of drought-hardy crops, late planting of drought-sensitive crops, or spreading of planting across the first 3 months of the season to moderate harm” (p. 355).

Another adaptation strategy consists in the adoption of ‘climate smart crops’ (Pushpalatha & Gangadharan, 2020) that’s to say those crops (or cultivars) that are more adapted to harsh conditions and can withstand changing climate (e.g. drought). Examples of these crops that are analysed in the literature include cassava (Egbebiyi, Lennard, *et al.*, 2019; Pushpalatha & Gangadharan, 2020), sorghum (Akinseye *et al.*, 2020) and maize (Nelimor *et al.*, 2019). For instance, Pushpalatha and Gangadharan (2020) highlight the resilience of cassava to changing climate and put that “Studies indicate cassava can tolerate a temperature level of up to 40 degrees C [...] Cassava has also an inbuilt mechanism to cope with water scarcity by leaf drooping [...] Studies also indicate a strong positive influence of elevated CO₂ of up to 700 ppm on the rate of photosynthesis and yield of cassava. Elevated CO₂ enhances the resilience of cassava to water stress and salinity. Similarly, the combined effect of elevated CO₂ and higher temperatures also increases the yield attributes of cassava”. In this context, there is an ongoing debate on the benefits of genetically modified crops in terms of climate change mitigation and adaptation (Quintero & Cohen, 2019).

An effective adaptation to climate change also implies fully exploiting the potential of ecosystem services for climate change resilience in rural as well as peri-urban areas (Mngumi, 2020). Indeed, Mngumi (2020) argue that “the potential for climate change resilience of well-managed peri-urban ecosystem services includes reducing the physical exposure of peri-urban areas to floods and droughts and minimizing climate change risks through increased socio-economic resilience to hazard impacts and provision of the carbon sequestration function”.

Resilience to drought is a central theme in the literature on climate change adaptation in the Sahel (Hadebe *et al.*, 2017; Kamali *et al.*, 2018, 2019; Naumann *et al.*, 2014; Nelimor *et al.*, 2019; Sidibé *et al.*, 2018). Kamali *et al.* (2019) suggest “improving adaptations to drought through investing in infrastructure, improving fertilizer distribution, and fostering economic development would contribute to drought resilience”. In this context, farmers in BF, as well as in the whole West Africa, adopted many water-harvesting techniques (e.g. stone rows, zai, half-moon) to mitigate the impacts of drought (Zouré *et al.*, 2019). Roncoli *et al.* (2001) point out that “Affordable grain, locally adapted seed varieties, labor saving technology and flexible credit are among the most needed inputs” (p. 119) to cope with drought in BF.

Irrigation is widely mentioned as a strategy to mitigate the vulnerability of rain-fed agriculture to climate change (Amjath-Babu *et al.*, 2016; Asafu-Adjaye, 2014; Cobbing & Hiller, 2019; Sylla, Pal, *et al.*, 2018; Ward *et al.*, 2014; Yamegueu *et al.*, 2019; Zidouemba, 2017). Nevertheless, increasing recourse to groundwater for irrigation and other uses (cf. pastoralism) may trigger communal violence (Döring, 2020). Indeed, Döring (2020) shows that “*lacking access to groundwater is associated with a higher risk of communal violence. Further, the effect of groundwater access on communal violence is conditioned by precipitation levels as well as population density*”. Irrigation is sometimes discussed in the analysed literature together with rainwater harvesting techniques (Biazin *et al.*, 2012; Bunclark *et al.*, 2018; Guan *et al.*, 2017; Lebel *et al.*, 2015; Zampaligré *et al.*, 2014).

As for the relationship between crop diversification and climate change adaptation, Pironon *et al.* (2019) suggest that “*Crop insecurity increases over time and with rising GHG emissions, but the potential for using agrobiodiversity for resilience is less altered. Climate change will therefore affect sub-Saharan agriculture but agrobiodiversity can provide resilient solutions in the short and medium term*” (p. 758). Meanwhile, in their analysis of the effects of climate stress on maize-based conservation agriculture systems, Steward *et al.* (2018) conclude that “*crop diversification did not notably improve conservation agriculture performance, but did increase its stability with heat stress*” (p. 194).

Livelihood diversification in another strategy for adaptation to climate change among agricultural households (Asafu-Adjaye, 2014; Lay *et al.*, 2009; Nielsen & Reenberg, 2010; Sissoko *et al.*, 2011; Tankari, 2020; Zorom *et al.*, 2013). Indeed, many rural households rely more and more on non-farm activities for gaining their livelihoods and ensuring their food security (D’haen *et al.*, 2014; Lay *et al.*, 2009; Tankari, 2020). For instance, Tankari (2020) conclude that “*Operating a nonfarm activity may therefore be a strategy to cope with the effects of rainfall variability among farm households in Burkina Faso*”. Chuku and Okoye (2009) identify four broad strategies to reduce vulnerability and increase resilience among farmers in SSA namely “*income and asset management strategies, farm production strategies, government programmes and support strategies and technological development strategies*” (p. 1524). Therefore, diversification of income-generating activities is considered as one of the risk management strategies.

Migration is considered as a further adaptation, coping strategy (Defrance *et al.*, 2017; Gray & Wise, 2016; Kniveton *et al.*, 2012; Roncoli *et al.*, 2001; Sanfo *et al.*, 2017; Zampaligré *et al.*, 2014; Zorom *et al.*, 2010). Defrance *et al.* (2017) estimate that “*without any adaptation measures, tens to hundreds million people could be forced to leave the Sahel by the end of this century*” (p. 6533). Referring to adaptation strategies of agro-pastoralists and pastoralists across BF, Zampaligré *et al.* (2014) put that “*Strategies of pastoralists included seasonal, annual and permanent migration and taking up of cereal cropping*” (p. 769).

Different factors affect the adoption of climate change adaptation strategies by farmers and rural populations (García de Jalón *et al.*,

2016, 2018; Zampaligré & Fuchs, 2019). In their analysis of the drivers of adaptation to climate change in African farms, Garcia de Jalon *et al.* (2016) found that the “[...] *common factors can be grouped into seven components, that is human capital, financial resources, infrastructure and technology, social interaction and governance, food security, dependence on agriculture and attitudes towards the environment*” (p. 779). Likewise, in their study on the effects of livelihoods assets/capitals (natural, physical, financial, human, social), that constitute ‘adaptive capacity’, on the adoption of adaptation strategies by smallholders in SSA, Garcia de Jalon *et al.* (2018) put that “*Human and social capital both displayed a positive and significant effect on the uptake of most adaptation practices. This finding suggests that the effect of less tangible kinds of capital such as knowledge, individual perceptions, farmers’ networks and access to information may be stronger than normally assumed*” (p. 38). Meanwhile, Zampaligré and Fuchs (2019) analyse the determinants of adopting climate-smart adaptation practices in the Sahelian agro-pastoral systems and conclude that “*a few assets were found to contribute significantly to the decision to adopt the assessed adaption practices. These include the possession of household and farm assets and equipment, membership in associations and assistance from government, farming experience of the household head, access to credit, as well as ownership and size of farmland*”.

Governance and institutions play a central role in determining the effectiveness of adaptation strategies (Brockhaus *et al.*, 2012; García de Jalón *et al.*, 2016; Makate, 2019). Indeed, referring to factors that explain the adoption of climate change adaptation strategies at farm level, Garcia de Jalon *et al.* (2016) conclude that “*adoption is associated predominantly with governance, civil rights, financial resources and education*” (p. 779). Moreover, Makate (2019) argues that “*enhancing the role of local institutions (LI) and incorporating indigenous knowledge (IK) in climate change adaptation planning can improve adoption and scaling success of climate-smart agriculture innovations*” thus calling for an active engagement of local communities and indigenous stakeholder institutions in the design, planning and implementation of climate adaptation activities. In this context, initiatives such as the “*4 per Thousand*” and “*Adapting African Agriculture*”, two initiatives adopted at the COP21 in Paris and the COP22 in Marrakesh (Morocco), can contribute to climate change mitigation and adaptation of African agriculture (Lal, 2019). Moreover, increasing attention has been devoted over the last decades to the mainstreaming of CSA into agricultural development plans as well as regional and national climate change adaptation policies and plans (Zougmore *et al.*, 2018). Referring to the National Adaptation Programme of Action (NAPA) in BF, Kalame *et al.* (2011) point out that agriculture, water resources and forestry are priority sectors in the NAPA. They assume that “*Factors determining the success of a NAPA are the level of funding, effectiveness of the coordination and implementation of the NAPA, and the importance decision makers give to adaptation*” (p. 535) and conclude that “*ecosystem-based approaches to adaptation can be used to enhance the resilience of communities and ecosystems*” (p. 535).

Anyway, an effective adaptation to climate change implies a timely and cost-effective access to climate information services

that meet the users' needs (Carr *et al.*, 2020; Chen *et al.*, 2018; Vaughan *et al.*, 2019; Wood *et al.*, 2014; Zampaligré & Fuchs, 2019). For instance, Wood *et al.* (2014) found that “*access to weather information, assets, and participation in social institutions are associated with households that have reported making farming changes*” (p. 163) in their study of smallholder adaptation strategies across SSA. In this context, access to extension services is an important determinant of adoption of climate-smart practices (Abegunde *et al.*, 2019; Ayantunde *et al.*, 2020; Boansi *et al.*, 2017; Callo-Concha, 2018; Zampaligré & Fuchs, 2019). Referring to Sub-Saharan Africa (SSA), Nkiaka *et al.* (2019) show that “*greater capacity building of personnel working for National Meteorological and Hydrological Services and Agricultural Extension staff and reinforcing and sustaining collaboration between different stakeholders (climate scientists, hydrologists, extension workers, farmers and other user groups), are essential factors for improving the uptake and utility of weather and climate services to enhance resilience to climate shocks in SSA*”. Likewise, Boansi *et al.* (2017) recommend that “*To enhance farmers' adaptive capacity, policy makers and various stakeholders need to contribute towards improving farmers' access to credit, markets, and extension services*” (p. 1).

Different financial products and services, based on climate information, have been promoted to adapt to climate change in developing countries. These instruments include insurance products such as “index insurance” (Siebert, 2016). However, also access to credit (Boansi *et al.*, 2017; Jahel *et al.*, 2017; Zampaligré & Fuchs, 2019) determine the level of investment in climate change adaptation and, consequently, their effectiveness and sustainability.

While most of the papers use household or farm as a unit of analysis without any disaggregation, others address gender issues (Bryan *et al.*, 2018; Huyer, 2016). In this respect, Huyer (2016) argues that “*Technologies to support resilience and adaptation to climate change by smallholder farmers can promote women's empowerment and the transformation of gender relations in addition to sustainably increasing agricultural production. But this will only happen if they are implemented in a framework of mutually reinforcing resources, women's control of assets, equitable decision making between women and men, and strengthened capacity*” (p. 105).

Evidence shows that not only the types of adaptation strategies but also the timing is important to consider. In this respect, Rippke *et al.* (2016) envisage “*three overlapping adaptation phases to enable projected transformational changes: an incremental adaptation phase focused on improvements to crops and management, a preparatory phase that establishes appropriate policies and enabling environments, and a transformational adaptation phase in which farmers substitute crops, explore alternative livelihoods strategies, or relocate*” (p. 605).

CONCLUSIONS

This paper represents the first comprehensive review on the multifaceted relationships between climate change and

agriculture in Burkina Faso. The review shows an increasing academic interest in the nexus between climate change and agriculture in BF and beyond (viz. West Africa, Sahel, Sub-Saharan Africa). The analysed literature focuses on crops (either alone or in mixed crop-livestock systems), while animal husbandry and, especially, fisheries are often overlooked. Likewise, most of the analysed documents deal with the adaptation to climate change by the Burkinabe farmers, herders, pastoralists and the rural populations in general. Nevertheless, many articles – such as those dealing with climate-smart agriculture – address simultaneously climate change mitigation and adaptation.

Evidence from the literature shows that Burkina Faso is experiencing climate change as characterized by warming, monsoonal precipitation recovery, and an increase in the occurrence of climate extremes. These climate tendencies are projected to continue although uncertainties affect climate simulations, especially regarding precipitation. A robust evidence of yield loss in BF, mainly driven by warming and increase in air temperature, emerges from the analysed literature. The negative impact of CC on crop yields results mainly from temperatures, for which climate models project an increase that is much larger with respect to changes in precipitation, which are still uncertain in climate projections. However, some scholars argue that elevated CO₂ concentrations (cf. ‘carbon fertilisation’) can help modulate yield loss. Yield losses and consequent decrease of agricultural production can have far-reaching effects in terms of food security and rural livelihoods in the country. In this context, different strategies are used by farmers to adapt to climate change; the categories of adaptation options include conservation agriculture and climate-smart agriculture, irrigation, crop diversification, increased inputs use and intensification, livelihoods diversification and migration. However, most of the analysed literature deals with adaptation to climate change in crop production while animal production and agro-forestry are often overlooked. Furthermore, the focus is mainly on agricultural and individual responses, while livelihoods strategies, such as diversification and migration, are less frequently addressed. As for adaptation in crop production, most case studies focus on potential for adaptation and adjustment of cropping systems (e.g. changing sowing/planting dates, sowing density, varieties, fertilizer management, irrigation) for major staple crops (e.g. millet, sorghum, maize). As for climate change adaptation in Burkinabe agriculture, more research is needed on the effectiveness of the different adaptation strategies and measures as well as the effects of the synergistic or antagonistic interactions between them. Furthermore, more attention should be devoted by researchers and scholars to community responses as well as tree-based and livestock-based ones. Another topic that deserves more emphasis in the research field is the contribution of ecosystem services to the resilience of rural communities in the face of the changing climate in BF and beyond (cf. West Africa, Sahel). It is also important to pay attention to the timing of the different adaptation strategies within adaptation phases to enable successful, smooth transformational changes in the Burkinabe agriculture.

All in all, it is crucial to devote much more attention to the dual relation between climate change and agriculture in order to contribute to the achievement of the SDGs in BF. In this respect, more emphasis should be put on approaches that deliver mitigation, adaptation and development co-benefits in rural areas of BF. By improving the understanding of the impacts of climate change on agriculture and rural livelihoods as well as the responses of Burkinabe populations, this paper provides valuable insights to researchers and decision makers alike in order both to refine and make more impactful research on climate change in BF in particular and West Africa in general and to inform policies aimed at climate change mitigation and/or adaptation.

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CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

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APPENDIX

Appendix 1: Geographical focus of research on the relationships between climate change and agriculture dealing with Burkina Faso

Geographical focus	Number of selected documents	References
Burkina Faso	50	Ayantunde <i>et al.</i> (2020); Barbier <i>et al.</i> (2009); Belem and Saqalli (2017); Belesova <i>et al.</i> (2019); Borona <i>et al.</i> (2016); Bostick <i>et al.</i> (2007); Bunclark <i>et al.</i> (2018); Coulibaly <i>et al.</i> (2014); D'haen <i>et al.</i> (2014); Di Leo <i>et al.</i> (2016); Dimobe <i>et al.</i> (2018); Fonta <i>et al.</i> (2015); Gahi <i>et al.</i> (2015); Gaisberger <i>et al.</i> (2017); Groten and Ocatre (2002); Hänke <i>et al.</i> (2016); Henderson <i>et al.</i> (2018); Heubes <i>et al.</i> (2013); Ingram <i>et al.</i> (2002); Jahel <i>et al.</i> (2017); Kalame <i>et al.</i> (2011); Kima <i>et al.</i> (2014); Kima <i>et al.</i> (2015); Kniveton <i>et al.</i> (2012); Lay <i>et al.</i> (2009); Lodoun <i>et al.</i> (2014); Mande <i>et al.</i> (2015); Mishra <i>et al.</i> (2008); Nielsen and Reenberg (2010); Rasmussen (2018); Rasmussen <i>et al.</i> (2014); Rasmussen <i>et al.</i> (2015); Rigolot <i>et al.</i> (2017); Roncoli <i>et al.</i> (2001); Sanfo <i>et al.</i> (2017); Serpantié <i>et al.</i> (2019); Sorgho <i>et al.</i> (2016); Tankari (2020); Traore and Owiyo (2013); vom Brocke <i>et al.</i> (2014); Waongo <i>et al.</i> (2014); Waongo <i>et al.</i> (2015); West <i>et al.</i> (2008); Wittig <i>et al.</i> (2007); Zampaligré and Fuchs (2019); Zampaligré <i>et al.</i> (2014); Zhang <i>et al.</i> (2019); Zidouemba (2017); Zorom <i>et al.</i> (2013); Zouré <i>et al.</i> (2019)
West Africa or Sahel*	69	Ahmed <i>et al.</i> (2015); Ahmed <i>et al.</i> (2016); Andam-Akorful <i>et al.</i> (2017); Arthur and Baidoo (2011); Asare-Kyei <i>et al.</i> (2017); Bayala <i>et al.</i> (2014); Belem <i>et al.</i> (2011); Berthou <i>et al.</i> (2019); Bhaduri <i>et al.</i> (2011); Bicher and Diedhiou (2018); Boansi <i>et al.</i> (2017); Boansi <i>et al.</i> (2019); Brockhaus <i>et al.</i> (2012); Busby <i>et al.</i> (2014); Callo-Concha (2016); Callo-Concha (2018); Defrance <i>et al.</i> (2017); Douxchamps <i>et al.</i> (2016); Egbebiyi <i>et al.</i> (2019); Egbebiyi <i>et al.</i> (2019); Egbendewe <i>et al.</i> (2017); Faye <i>et al.</i> (2018); Ferner <i>et al.</i> (2018); Garnot <i>et al.</i> (2018); Guan <i>et al.</i> (2015); Guan <i>et al.</i> (2017); Haussmann <i>et al.</i> (2012); Johnson and Brown (2014); Jung <i>et al.</i> (2012); Klutse <i>et al.</i> (2018); Lahmar <i>et al.</i> (2012); Lambin <i>et al.</i> (2014); Lokonon <i>et al.</i> (2019); Luedeling and Neufeldt (2012); McPeak (2017); Mertz (2011); Mertz <i>et al.</i> (2010); Mertz <i>et al.</i> (2016); Nelimor <i>et al.</i> (2019); Oguntunde <i>et al.</i> (2017); Olusegun <i>et al.</i> (2018); Ouédraogo <i>et al.</i> (2017); Paeth (2011); Palazzo <i>et al.</i> (2017); Parkes <i>et al.</i> (2015); Parkes <i>et al.</i> (2018); Proud and Rasmussen (2011); Rauch <i>et al.</i> (2019); Salack <i>et al.</i> (2015); Salack <i>et al.</i> (2016); Scheiter and Savadogo (2016); Siebert (2016); Sissoko <i>et al.</i> (2011); Sossa <i>et al.</i> (2017); Stith <i>et al.</i> (2016); Sultan <i>et al.</i> (2013); Sultan <i>et al.</i> (2014); Sultan <i>et al.</i> (2019); Sultan <i>et al.</i> (2019); Sylla <i>et al.</i> (2015); Sylla <i>et al.</i> (2018a); Sylla <i>et al.</i> (2018b); Taylor <i>et al.</i> (2002); Traoré <i>et al.</i> (2011); Ugbaje <i>et al.</i> (2019); van Oort and Zwart (2018); van Wesenbeeck <i>et al.</i> (2016); Wang <i>et al.</i> (2017); Zorom <i>et al.</i> (2010)
Sub-Saharan Africa or Africa**	98	Abidoye and Odusola (2015); Amjath-Babu <i>et al.</i> (2016); Asafu-Adjaye (2014); Azzarri and Signorelli (2020); Barrios <i>et al.</i> (2008); Bennetzen <i>et al.</i> (2016); Bodin <i>et al.</i> (2016); Bryan <i>et al.</i> (2018); Buhaug <i>et al.</i> (2015); Calzadilla <i>et al.</i> (2013); Chaney <i>et al.</i> (2014); Chen <i>et al.</i> (2018); Choptiany <i>et al.</i> (2017); Cobbing and Hiller (2019); Cooper <i>et al.</i> (2008); Corbeels <i>et al.</i> (2014); Dale <i>et al.</i> (2017); de Vrese <i>et al.</i> (2018); Descheemaeker <i>et al.</i> (2016); Dixon and Stringer (2015); Doelman <i>et al.</i> (2018); Döring (2020); Dunning <i>et al.</i> (2016); Egbendewe (2018); Fanzo <i>et al.</i> (2018); Faramarzi <i>et al.</i> (2013); Folberth <i>et al.</i> (2014); Garcia de Jalon <i>et al.</i> (2018); Garrity <i>et al.</i> (2010); Gray and Wise (2016); Hadebe <i>et al.</i> (2017); Haile (2005); Hasegawa <i>et al.</i> (2018); Henderson <i>et al.</i> (2016); Henderson <i>et al.</i> (2017); Hendrix and Glaser (2007); Hoffman <i>et al.</i> (2018); Huyer (2016); Jarvis <i>et al.</i> (2012); Jones and Thornton (2009); Jun (2017); Kamali <i>et al.</i> (2018); Kamali <i>et al.</i> (2019); Kamoni and Gicheru (2015); Lebel <i>et al.</i> (2015); Liu <i>et al.</i> (2013); Lobell <i>et al.</i> (2008); Lobell <i>et al.</i> (2013); López-Carr <i>et al.</i> (2014); Mahe <i>et al.</i> (2013); Naumann <i>et al.</i> (2014); Niles and Brown (2017); Nyboer <i>et al.</i> (2019); Ogundari <i>et al.</i> (2017); Onyutha (2018a); Oyekale (2015); Perez <i>et al.</i> (2007); Pironon <i>et al.</i> (2019); Prestele and Verburg (2020); Quintero and Cohen (2019); Ramin and McMichael (2009); Ramirez-Villegas <i>et al.</i> (2013); Richardson <i>et al.</i> (2018); Ringius (2002); Rippke <i>et al.</i> (2016); Rosenthal and Ort (2012); Rudi <i>et al.</i> (2012); Schlenker and Lobell (2010); Seo (2014); Seo <i>et al.</i> (2009); Serdeczny <i>et al.</i> (2017); Sheffield <i>et al.</i> (2014); Shi and Tao (2014); Sidibé <i>et al.</i> (2018); <i>et al.</i> (2019); Sonwa <i>et al.</i> (2017); Steward <i>et al.</i> (2018); Tabeau <i>et al.</i> (2017); Tesfaye <i>et al.</i> (2015); Thomas and Nigam (2018); Thornton and Herrero (2014); Thornton and Herrero (2015); Thornton <i>et al.</i> (2011); Tittonell <i>et al.</i> (2012); Torquebiau (2017); van Loon <i>et al.</i> (2019); von Uexkull (2014); von Uexkull <i>et al.</i> (2016); Vrieling <i>et al.</i> (2008); Vrieling <i>et al.</i> (2013); Waha <i>et al.</i> (2013); Waha <i>et al.</i> (2016); Waha <i>et al.</i> (2013); Wang (2005); Ward <i>et al.</i> (2014); Witmer <i>et al.</i> (2017); Wood <i>et al.</i> (2014); Yang <i>et al.</i> (2013)

* This category also includes documents dealing with BF and at least another West African country

** This category includes at least an African country outside West Africa

Appendix 2: Agriculture subsectors in the analysed literature on the relationships between climate change and agriculture in Burkina Faso

Agriculture subsector	Number of selected documents	References
Crop production	82	Ahmed <i>et al.</i> (2015); Amjath-Babu <i>et al.</i> (2016); Andam-Akorful <i>et al.</i> (2017); Barrios <i>et al.</i> (2008); Belesova <i>et al.</i> (2019); Bhaduri <i>et al.</i> (2011); Bodin <i>et al.</i> (2016); Bostick <i>et al.</i> (2007); Bunclark <i>et al.</i> (2018); Cobbing and Hiller (2019); Cooper <i>et al.</i> (2008); Dale <i>et al.</i> (2017); Dunning <i>et al.</i> (2016); Egbebiyi <i>et al.</i> (2019); Egbebiyi <i>et al.</i> (2019); Faramarzi <i>et al.</i> (2013); Faye <i>et al.</i> (2018); Folberth <i>et al.</i> (2014); Fonta <i>et al.</i> (2015); Gahi <i>et al.</i> (2015); Groten and Ocatre (2002); Guan <i>et al.</i> (2015); Guan <i>et al.</i> (2017); Hadebe <i>et al.</i> (2017); Haussmann <i>et al.</i> (2012); Hoffman <i>et al.</i> (2018); Jarvis <i>et al.</i> (2012); Jun (2017); Jung <i>et al.</i> (2012); Kamali <i>et al.</i> (2018); Kamali <i>et al.</i> (2019); Kima <i>et al.</i> (2014); Lebel <i>et al.</i> (2015); Liu <i>et al.</i> (2013); Lodoun <i>et al.</i> (2014); Mahe <i>et al.</i> (2013); Mishra <i>et al.</i> (2008); Nelimor <i>et al.</i> (2019); Oguntunde <i>et al.</i> (2017); Onyutha (2018a); Paeth (2011); Parkes <i>et al.</i> (2015); Parkes <i>et al.</i> (2018); Pironon <i>et al.</i> (2019); Quintero and Cohen (2019); Ramirez-Villegas <i>et al.</i> (2013); Rauch <i>et al.</i> (2019); Rosenthal and Ort (2012); Salack <i>et al.</i> (2015); Salack <i>et al.</i> (2016); Schlenker and Lobell (2010); Serpantié <i>et al.</i> (2019); Sheffield <i>et al.</i> (2014); Shi and Tao (2014); Sidibé <i>et al.</i> (2018); Siebert (2016); Steward <i>et al.</i> (2018); Sultan <i>et al.</i> (2013); Sultan <i>et al.</i> (2014); Sultan <i>et al.</i> (2019); Sultan <i>et al.</i> (2019); Sylla <i>et al.</i> (2018a); Sylla <i>et al.</i> (2018b); Tesfaye <i>et al.</i> (2015); TITTONELL <i>et al.</i> (2012); Traoré <i>et al.</i> (2011); Ugbaje <i>et al.</i> (2019); van Loon <i>et al.</i> (2019); van Oort and Zwart (2018); vom Brocke <i>et al.</i> (2014); Vrieling <i>et al.</i> (2008); Vrieling <i>et al.</i> (2013); Waha <i>et al.</i> (2013); Waha <i>et al.</i> (2013); Wang <i>et al.</i> (2017); Waongo <i>et al.</i> (2014); Waongo <i>et al.</i> (2015); Ward <i>et al.</i> (2014); Wood <i>et al.</i> (2014); Yang <i>et al.</i> (2013); Zhang <i>et al.</i> (2019); Zouré <i>et al.</i> (2019)
Animal production and pastoralism	7	Arthur and Baidoo (2011); Ferner <i>et al.</i> (2018); Henderson <i>et al.</i> (2017); McPeak (2017); Rasmussen <i>et al.</i> (2014); Rasmussen <i>et al.</i> (2015); Seo <i>et al.</i> (2009)
Crop production animal production (e.g. agro-pastoral systems; mixed crop-livestock systems)	96	Abidoye and Odusola (2015); Asafu-Adjaye (2014); Asare-Kyei <i>et al.</i> (2017); Ayantunde <i>et al.</i> (2020); Azzarri and Signorelli (2020); Barbier <i>et al.</i> (2009); Bennetzen <i>et al.</i> (2016); Boansi <i>et al.</i> (2017); Boansi <i>et al.</i> (2019); Borona <i>et al.</i> (2016); Brockhaus <i>et al.</i> (2012); Bryan <i>et al.</i> (2018); Buhaug <i>et al.</i> (2015); Busby <i>et al.</i> (2014); Callo-Concha (2016); Callo-Concha (2018); Calzadilla <i>et al.</i> (2013); Chaney <i>et al.</i> (2014); Chen <i>et al.</i> (2018); Choptiany <i>et al.</i> (2017); Corbeels <i>et al.</i> (2014); D'haen <i>et al.</i> (2014); Defrance <i>et al.</i> (2017); Descheemaeker <i>et al.</i> (2016); Dixon and Stringer (2015); Döring (2020); Douchamps <i>et al.</i> (2016); Egbendewe <i>et al.</i> (2017); Fanzo <i>et al.</i> (2018); Garcia de Jalon <i>et al.</i> (2018); Garnot <i>et al.</i> (2018); Gray and Wise (2016); Haile (2005); Hasegawa <i>et al.</i> (2018); Henderson <i>et al.</i> (2016); Henderson <i>et al.</i> (2018); Hendrix and Glaser (2007); Huyer (2016); Ingram <i>et al.</i> (2002); Johnson and Brown (2014); Jones and Thornton (2009); Kamoni and Gicheru (2015); Kima <i>et al.</i> (2015); Kniveton <i>et al.</i> (2012); Lahmar <i>et al.</i> (2012); Lay <i>et al.</i> (2009); Lobell <i>et al.</i> (2008); Lobell <i>et al.</i> (2013); Lokonon <i>et al.</i> (2019); López-Carr <i>et al.</i> (2014); Mertz (2011); Mertz <i>et al.</i> (2010); Mertz <i>et al.</i> (2016); Naumann <i>et al.</i> (2014); Nielsen and Reenberg (2010); Niles and Brown (2017); Ouedraogo <i>et al.</i> (2017); Oyekale (2015); Palazzo <i>et al.</i> (2017); Perez <i>et al.</i> (2007); Prestele and Verburg (2020); Ramin and McMichael (2009); Rasmussen (2018); Richardson <i>et al.</i> (2018); Rigolot <i>et al.</i> (2017); Ringius (2002); Rippke <i>et al.</i> (2016); Roncoli <i>et al.</i> (2001); Rudi <i>et al.</i> (2012); Sanfo <i>et al.</i> (2017); Seo (2014); Serdeczny <i>et al.</i> (2017); Sissoko <i>et al.</i> (2011); Sonwa <i>et al.</i> (2017); Sorgho <i>et al.</i> (2016); Sossa <i>et al.</i> (2017); Sylla <i>et al.</i> (2015); Tankari (2020); Thornton and Herrero (2014); Thornton and Herrero (2015); Thornton <i>et al.</i> (2011); Torquebiau (2017); Traore and Owiyo (2013); van Wesenbeeck <i>et al.</i> (2016); von Uexkull (2014); von Uexkull <i>et al.</i> (2016); Waha <i>et al.</i> (2016); Wang (2005); West <i>et al.</i> (2008); Witmer <i>et al.</i> (2017); Wittig <i>et al.</i> (2007); Zampaligré and Fuchs (2019); Zampaligré <i>et al.</i> (2014); Zidouemba (2017); Zorom <i>et al.</i> (2010); Zorom <i>et al.</i> (2013)
Agriculture and forestry (e.g. agroforestry)	31	Ahmed <i>et al.</i> (2016); Bayala <i>et al.</i> (2014); Belem and Saqalli (2017); Belem <i>et al.</i> (2011); Berthou <i>et al.</i> (2019); Bicher and Diedhiou (2018); Coulibaly <i>et al.</i> (2014); de Vrese <i>et al.</i> (2018); Di Leo <i>et al.</i> (2016); Dimobe <i>et al.</i> (2018); Doelman <i>et al.</i> (2018); Egbendewe (2018); Gaisberger <i>et al.</i> (2017); Garrity <i>et al.</i> (2010); Hänke <i>et al.</i> (2016); Heubes <i>et al.</i> (2013); Jahel <i>et al.</i> (2017); Kalame <i>et al.</i> (2011); Klutse <i>et al.</i> (2018); Lambin <i>et al.</i> (2014); Luedeling and Neufeldt (2012); Mandé <i>et al.</i> (2015); Ogundari <i>et al.</i> (2017); Olusegun <i>et al.</i> (2018); Proud and Rasmussen (2011); Scheiter and Savadogo (2016); Sidibe <i>et al.</i> (2019); Stith <i>et al.</i> (2016); Tabeau <i>et al.</i> (2017); Taylor <i>et al.</i> (2002); Thomas and Nigam (2018)
Fisheries	1	Nyboer <i>et al.</i> (2019)