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CLIMATE CHANGE AND ITS IMPACT ON CROP YIELDS IN SUB-SAHARAN AFRICA: NEW EVIDENCES FROM MODERN STUDIES

Research article

Abstract

Agriculture is the most vulnerable economic sector to climate change. The sustainable crop production is under the question due to climate change. There is uncertainty regarding climate change projections in the near future. There is also uncertainty concerning crop yields to these changes. Particularly, Sub-Saharan Africa is strongly dependent on the adverse climate changes. It is expected to increase food insecurity in this region in response to climate variability. This paper examines the impact of climate change on the crop yields based on recent studies. Moreover, the paper focuses on staple crops such as maize, millet, groundnuts, cassava and sorghum in Sub-Saharan Africa.

Keywords: climate change, crop yields, Sub-Saharan Africa, forecast, crop models.

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ИЗМЕНЕНИЕ КЛИМАТА И ЕГО ВЛИЯНИЕ НА УРОЖАЙНОСТЬ СЕЛЬСКОХОЗЯЙСТВЕННЫХ КУЛЬТУР В СТРАНАХ АФРИКИ К ЮГУ ОТ САХАРЫ: НОВЫЕ ДАННЫЕ СОВРЕМЕННЫХ ИССЛЕДОВАНИЙ

Научная статья

Аннотация

Сельское хозяйство является наиболее уязвимым сектором экономики в условиях изменения климата. Устойчивое производство сельскохозяйственных культур находится под вопросом в связи с изменением климата. Существует неопределенность прогнозов изменения климата в ближайшем будущем. Наблюдается непредсказуемость в отношении реакции урожайности сельскохозяйственных культур на эти изменения. В частности, страны Африки к югу от Сахары сильно зависят от неблагоприятных климатических изменений. Ожидается, что продовольственная нестабильность в данном регионе возрастет. В данной статье рассматривается вопрос изменения климата на урожайность сельскохозяйственных культур на основе обзора современных исследований. Особое внимание в работе уделяется ключевым сельскохозяйственным культурам региона Африки к югу от Сахары, таким как кукуруза, просо, земляные орехи, маниока и сорго.

Ключевые слова: изменение климата, урожайность сельскохозяйственных культур, Африка к югу от Сахары, прогноз, модели сельскохозяйственных культур.

1. Introduction

Many factors influence food production and agriculture. Adverse changes in climate are expected to affect directly agricultural production and agricultural system in the next few decades. Agriculture is at the intersection of three major challenges in the context of climate change: achieving food security, adapting to the impacts of climate change and reducing emissions [1]. Due to changes in atmosphere CO_2 concentration, changes in patterns of temperature and precipitation could affect the crop yields. Moreover, the resilience of production crops to climate change, particularly global warming and shift in the precipitation patterns, is highly critical for food security in the world. For example, warming trends reduce global yields by approximately 1.5% by decade without sustainable adaptation [2]. According to Müller et al., the main impact of climate change on crops is decreasing the crop yields which tend to the rising risk of food insecurity, poverty and malnutrition [3].

Hence, agricultural production systems meet a number of crucial challenges in the context of an increasing food demand for a growing population, loss of biodiversity, emerging pests and diseases, and finally the adverse effects of climate change [4].

Furthermore, Sub-Saharan African (SSA) countries are highly dependent on agricultural sector. Due to climate change, a number of uncertainties related to rainfed lands and challenges for farmers are expected to increase. As a result, agricultural production in Sub-Saharan Africa is extremely vulnerable to the effects of climate change. That leads to growing attention from the academic society to investigate possible consequences of climate change, particularly on the crop yields.

The purpose of this paper is to review recent research works on the topic as: the impact of climate change on crop yields in Sub-Saharan African countries. Based on the collected sample of papers I deal with the following tasks: (1) to investigate the databases, models and approaches; (2) to compare results and to identify similarities and differences; (3) finally summarize findings and reveal what climate variables will be responsible for future changes in the yields of staple crops (cereals, tubers and roots) in the Sub-Saharan African region.

2. Relationship between climate change and agriculture in Sub-Saharan Africa

2.1. Sub-Saharan Africa and the agricultural sector

Agriculture in Sub-Saharan Africa is associated with the several underlying trends that influence economic development of the region as a whole. These trends comprise rapid growth of population, rapid urbanization, rural diversification, structural transformation [2].

The agricultural sector is the key economic sector which has a high share in GDP and plays the crucial role in employment in SSA. On average the agricultural share of total GDP in 2017 among Sub-Saharan African countries is accounted for 15.8% [5]. It is important to note that Sub-Saharan Africa include 46 countries based on the list of the World Bank. Figure 1 shows the share of the agricultural sector of total GDP for some countries of this region. More important is that there are many countries in SSA which the share of the agricultural sector of total GDP is higher than 15 % (see Figure 1). For example, Chana presents about 20 %, Uganda is about 25%, Ethiopia and Kenya, approximately 34% and 35%. The share of agricultural sector in Chad is the highest one, approximately 49 %.

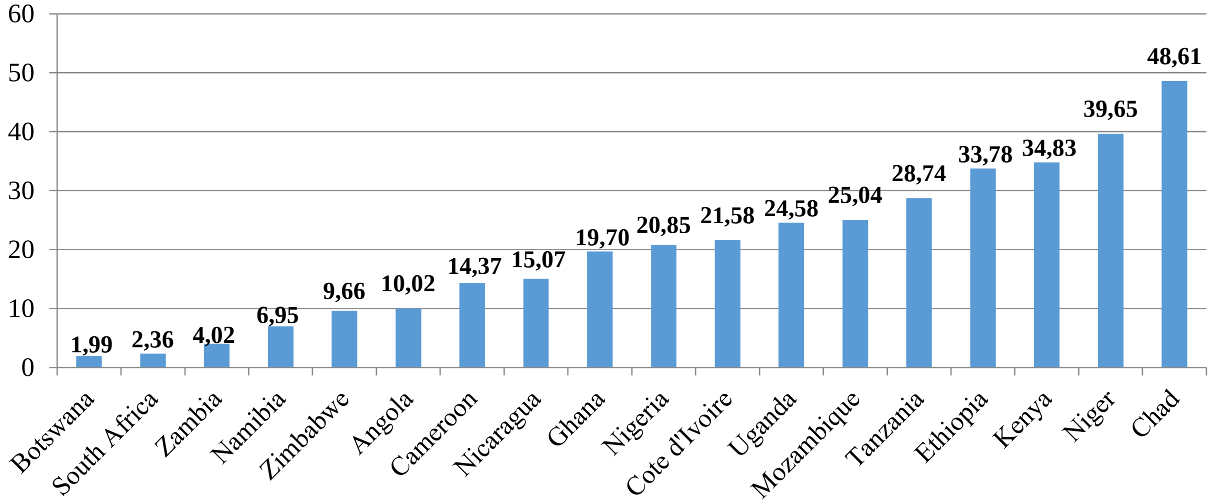

Figure 1 – Agriculture as a share of total GDP in Sub-Saharan African countries, in 2017
Source: Own calculations based on the World Development Indicators [5]

To better understand the significance of agricultural contribution to GDP, one may compare with other countries over the world. For example, in 2017, the share of the agricultural sector of total GDP in European Union is about 1.6%, in Mexico (3.4 %), in Brazil (4.6%), in China (7.6%), in India (15.6%) (see Figure 2). Hence, the share of the agricultural sector of total GDP in Sub-Saharan African counties is still extremely highly.

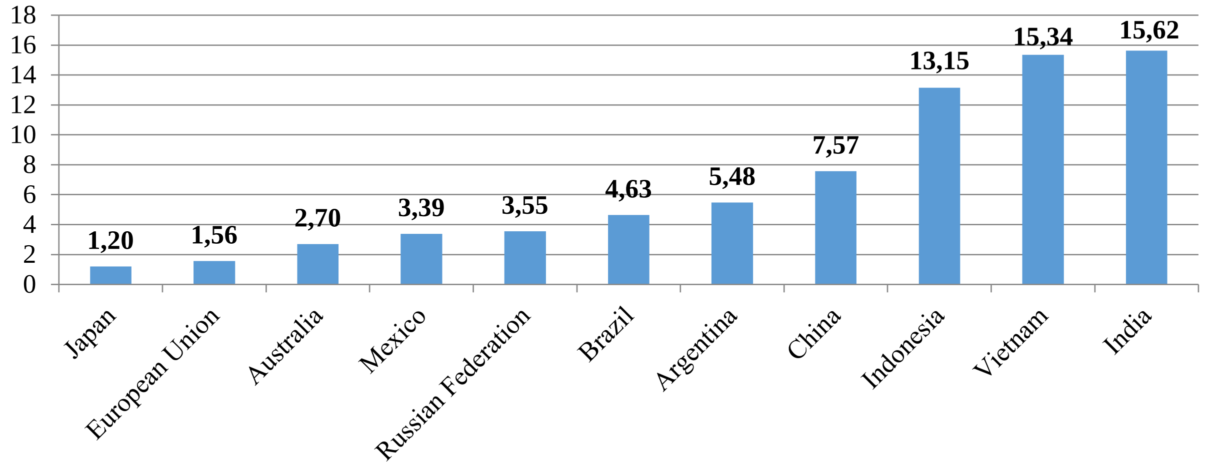

Figure 2 – Agriculture as a share of total GDP in other countries in the world, in 2017
Source: Own calculations based on the World Development Indicators [5]

In addition, the sector of agriculture creates many jobs in SSA. The main tendency is that more than half of total workforce is provided by agriculture. As illustrated in Figure 3, the share of employment in agriculture by the example of three regions in the world such as Sub-Saharan Africa, Latin America and Caribbean, and East Asia and Pacific decreased from 1997 to 2017. However, in SSA agriculture has still been the key source of employment.

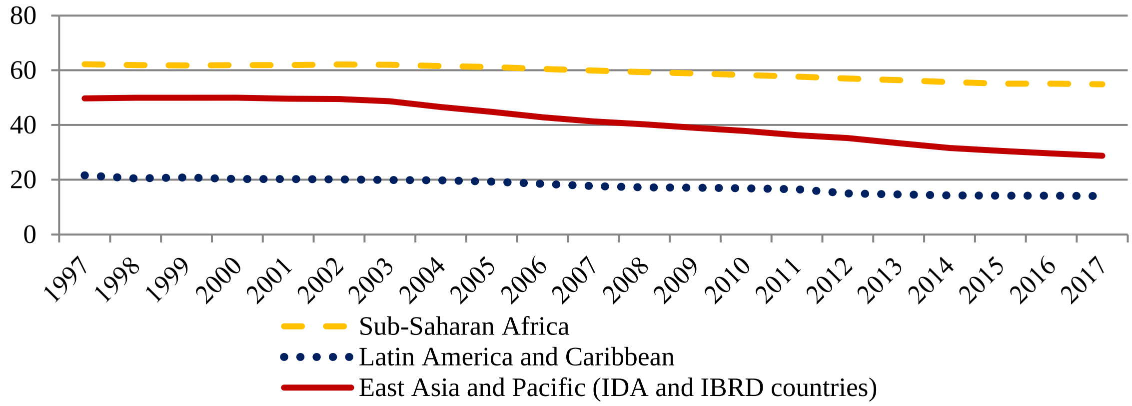

Figure 3 – Employment in Agriculture, from 1997 to 2017 (% of total employment)
Source: Own calculations based on the World Development Indicators [5]

Furthermore, the population of Sub-Saharan African countries is significantly growing every year. Between 1950 and 2010 it grew from 186 million to 856 million people (see Figure 4). It is expected that the population of Sub-Saharan Africa could be as large as 2.7 billion people. That will lead to an increasing agricultural consumption. In that context the sustainable agricultural production is a crucial foundation for sustainable economic development.

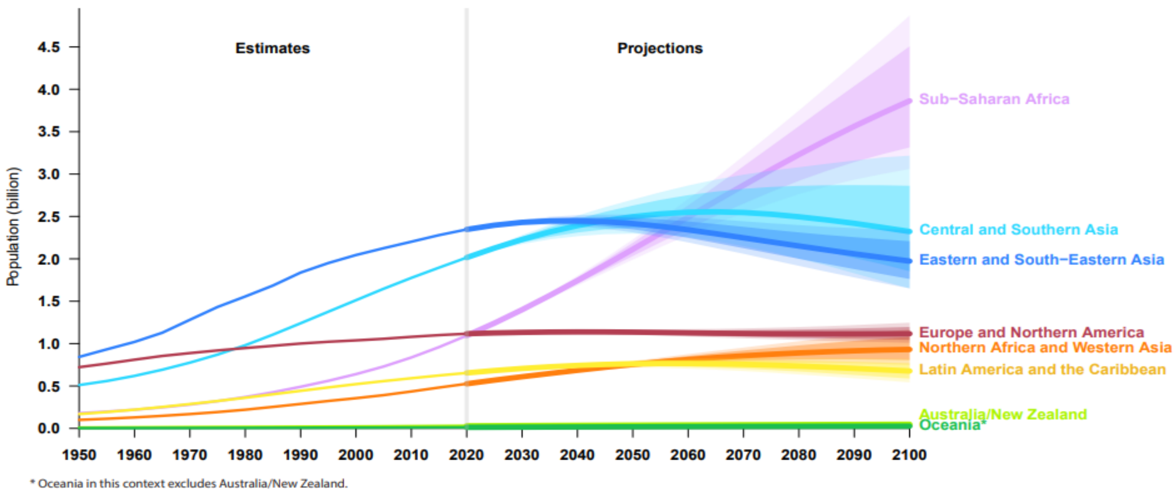

Figure 4 – Estimations and projections of population in the world by regions
Source: Data Booklet, United Nations, Department of Economic and Social Affairs [6, P.4]

Note that Sub-Saharan African region remains the highest share of malnourished population in the world. In spite of reduction of malnutrition from 33% in 1990-1992 to 23% in 2014-2016, the percentage of malnutrition stays the highest among developing regions [1]. As Food Agriculture Organization states that the number of undernourished people in Sub-Saharan Africa has mainly due to the impact of conflict and climate change [7]. Hence, climate change brings the risks to the African agricultural systems, affecting crop, livestock and fisheries productivity.

2.2. Sub-Saharan Africa and climate change

Future climate change is expected to have the negative impacts on agriculture in Sub-Saharan Africa through different ways. It means climate change will affect direct and indirect effect. As stated Henderson et al., adverse climate change is likely to will push people out of rural areas into urban areas so that urbanization "provides an "escape" from the effect of deteriorating climate on agricultural productivity" [8, P.61].

A key point is direct effect of climate change is connected to crop yields. Generally, plant growing is strongly dependent on weather event, especially in Sub-Saharan Africa. Main determinants (weather conditions or weather variables) of crop growth are precipitation, average temperature, the evapotranspiration rate, quality of soil. Moreover, rainfed lands dominate in Sub-Saharan Africa and rainfed agriculture accounts for more than 95% of farmed land in SSA [9]. The production of the following crops as maize, millet and sorghum are mostly occurred in rainfed areas [10]. It should be highlighted that maize is the largest crop of summer season, particularly across Eastern and South Africa countries of SSA region. It suggests that an increasing pressure on rainfed cropland is expected to create adverse conditions to production of the main staple crops and then a rise of crop yield will be under threat.

For this reason, making projections of climate change to crop yields is the pivotal topic for Sub-Saharan African countries. There are a large number of studies addressing questions related to climate change and how it influences crop yields in Sub-Saharan African region [10], [11], [12], [13], [14], [15]. The question is: how would changes in temperature and precipitation decrease average production of main crops in SSA will be addressed in the next sections.

3. Analyze of recent literature on climate change and its impacts in Sub-Saharan Africa

3.1 The sample of papers

I take into consideration the papers which study the impact of climate change on staple crops in Sub-Saharan Africa. It is important to highlight that maize, millet, groundnuts, cassava, wheat, rice and sorghum are one of the most vital sources of calories, fat and protein in this region. However, rice is usually excluded from studies because by contrast of the other staple crop, production of rice requires significant irrigation. Hence, the selected papers mostly cover four or five crops. A detail analysis of the sample which is presented by three contemporary papers provides a deep insight about methodology and the main results in the world scientific literature. The chosen papers are published from 2010 to 2015 in the following journals as: Climate Change, American Journal of Climate Change, and Environmental Research Letters (see Table 1).

Table 1 – The list of selected papers

№	Article
1	Ahmed, K. F., Wang, G., Yu, M., Koo, J., & You, L. (2015). Potential impact of climate change on cereal crop yield in West Africa. *Climatic Change*, 133(2), P. 321-334.
2	Blanc, É. (2012). The impact of climate change on crop yields in Sub-Saharan Africa. *American Journal of Climate Change*, 1(1), P. 1-13.
3	Schlenker, W., & Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. *Environmental Research Letters*, 5(1), P. 1-8

Source: Own illustrations.

In addition, the paper of Roudier et al. is taken into account as controlled paper. More details, authors Roudier et.al. collected 16 papers which cover the period between 1996 and 2010 to estimate "the potential impact of climate change" on crop yields in West African countries [16]. The West African region is a part of the Sub-Saharan African region and highly dependent area in SSA to climate change issues. For this reason, the work of Roudier et al. may provide a full picture regard different methods and variables that were used in the analysis and were highlighted the key challenges for making prediction of the impact of climate change on agriculture in Sub-Saharan African Region.

Furthermore, the main objective of this work is to reveal uncertainties which are the challenges for making reliable future scenarios of agricultural production. According to Roudier et al., quantifying the impacts of climate change on crop yield is a complicated task due to several large uncertainties in the regional projections of climate change, in the response of crop to environmental changes such as rainfall, temperature, CO_2 concentration, and therefore, in the connection between climate models and crop productivity functions [16].

3.2. Theoretical framework about projections of future climate

A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change [7], [17].

In the climate change literature two general approaches are implemented to convert climate scenarios into feasible agriculture yields [16], [18], [19]. There are an empirical (statistical) modeling and a process-based crop modeling. The goal of both approaches is to assess response of crop productivity to climate. It is necessarily to describe the main aspects of both approaches. In case of empirical crop models in which statistical relationships are derived from observations, connecting crop yields in a given location to local climate variables, are relatively easy to compute, evaluate, calibrating and validating a robust statistical model demands long a time series of yields and climate [16].

In contrast to the first approach, the reproduction of climate impact on the observed yield at large spatial scale is more complicated by using process-based crop modeling [19]. It means that process-based crop modeling does not provide complete picture change of climate at large scale.

It important to underline that there is a third approach by named “Ricardian analysis” to estimate impact of climate change on crop yields where adaptation strategies have been taken into consideration. Previous two universal mentioned above approached do not include aspect as adaptation into analysis. This approach was introduced and constructed by scholar Mendelsohn et al. The main point is that “Ricardian approach” concentrates on land values and farm revenues instead of crop yields. It means that monetary variables are a basis for this approach. The input variables are temperature, precipitation or carbon dioxide. This approach would allow us to measure the economic value of different activities and consequently to check if the economic impacts included by the production-function approach. However, this approach does not allow considering tendencies of future yields that it can be explained why it is not often applied. Moreover, first time this approached was adopted for the USA. Furthermore, “Ricardian analysis” is implemented in studying climate in African countries [17].

3.3 Results and discussion based of chosen papers

Before the consideration the three selected works, the findings from the paper of Roudier et al. will be discussed. As noted above, the authors made the meta-base analysis by combined outcomes from 16 articles in order to examine amplitude and uncertainty of impacts on crop productivity in West African countries. The analysis shows the following heterogeneous results.

Firstly, to concentrate more precisely to a response of the yield to climate change, the yield change without the CO_2 fertilization effect has been taken into account. Furthermore, process-based crop models and empirical crop models have provided mostly similar outcomes for future yields.

Secondly, main cultivated crops in Sub-Saharan African region have mainly been taken for account by authors in 16 papers. However, Roudier et al. stated that mostly authors have not focused on specifying cultivar. It is important to include for consideration various cultivars of one kind of crop in the future studies, because it will give more precisely results.

Thirdly, CO_2 fertilization effect has been investigated into 16 papers. On the one hand, some studies find out that there is large extent of uncertainties “in the quantification of agricultural impacts is the effect of CO_2”. On the other hand, other studies have not revealed large discrepancies between with and no CO_2 fertilization scenarios.

Fourthly, despite of a large dispersion of future yield changes, ranging from a loss of yield about - 50% to an increase of yield + 90%, the median value provides a negative loss of yield approximately 11 %.

Fifty, negative climate change impacts on crop productivity are more severe under high intensity of warming scenarios, with a median yield loss about 15% for the most intense warming scenarios.

To sum up, Roudier et al. revealed from results of 16 papers that the negative climate change impact arises from a temperature increase that leads to decline the crop cycle duration and generate higher water stress via higher evapotranspiration demand [16].

Now, three collected papers will be examined. The finding from these papers will partly be corresponded with results that have been considered above. The main elements of analysis such as geographical areas (number of countries), types of crop, baseline and horizon, climate models and crop models, scenarios are presented in Table 2.

Table 2 – Summary of selected articles

Author	Sample (countries)	Types of crop	Baseline	Horizon	Climate model	Crop model	Scenario
Ahmed et. al. (2015)	West Sub-Saharan African countries: 13 countries	Maize, sorghum and millet	1980-1998	2041-2059	MIROC-ESM, CESM.	Process-based crop model DSSAT based on present-day country-level yield	The calibration model to project the future yields. Two scenarios were implied
Blanc (2012)	37 countries in SSA region	Millet, maize, sorghum and cassava	1961-2002	until 2100	GCMs (General Circula-tion Models)	Empirical modelling	A1F1, A2, B1, B2
Schlenker Lobell (2010)	SSA region	Maize, sorghum millet, groundnut and cassava	1961-2002	until 2055	GCMs	Empirical modelling	A1B

Source: Own illustrations.

It is important to note that two papers from the sample investigate mostly all countries from Sub-Saharan African region and the paper of Ahmed et al. covers 13 countries of West Sub-Saharan Africa (see Table 2). A further step is to focus on implemented methods, approaches, models and databases.

In the paper by Ahmed et. al., the process-based crop model was used to study the impact of climate change on cereal crop yields and then the following questions were addressed as: (1) "what climate variables can be implemented to make prediction for future changes in the productivity and yield of crop like maize, sorghum and millet? (2) How could Decision Support System for Agrotechnology Transfer (DSSAT) model be calibrated in order to simulate the observed yields of cereal crops under country-level?" Given process-based crop model DSSAT combines weather and soil data, together crop management strategies [19].

In spite of the consideration only West Africa region out Sub-Saharan African region, authors pointed out that there was the diversity of climate levels which was represented by hot desert climate, hot semi-arid climate and tropical climate. Moreover, the future climate data with period from 2041 to 2059 were arisen from two models as the regional climate model RegCM4.3.4 which has been elaborate by Giorgi (2012, seen from the paper Ahmed et. al., 2015) and the Community Land Model version 4.5 which was introduced by Olsen (2010, seen from the paper Ahmed et. al., 2015). The research was based on the following climate models such as MIROC-ESM and CESM (see Table 2).

In result, future crop yields are expected to decrease due to intended changes in temperature and precipitation [19]. However, crop response of maize, millet and sorghum to climate change will be different. In order to have full picture, it needs to include date of temperature of growing season and precipitation under plant life cycle, other words various growth stages of plant. Although increasing temperature leads to decline crop yield, present-day yield and growing season rainfall have a positive correlation. To summarize discussion and results of research in the papers Ahmed et. al., crop responses to climate change are heterogeneity due to the uncertainties [19].

In the paper by Blanc, statistical modelling was applied to estimate the impact of climate change on the main crop yields in SSA region. Table 2 shows that Blanc used output production function and separate equations for to relation to four analyzing crop such as millet, maize, sorghum and cassava [20]. Panel data were employed where area harvested (in hectares, Ha) and yields (in tonnes/Ha) were derived from FAO database, further, the weather data were obtained from CRU TS 2.1 dataset and Mauna Loa Observatory (see Table 3).

It is important to consider in more detail the weather variables. Generally, average precipitation and temperature variables are taken as main indicators of climate change. Standardized precipitation index (SPI), evapotranspiration, drought and floods were also included in the analysis.Additionally, evapotranspiration rate is more complex indicator which combines the loss of water from soils and from crops to show crop water use. Furthermore, the evapotranspiration rate was determined by the Hargreaves equation. In order to prevent multicollinearity, two models as T-P and ET-SPI were implemented, where T-P model contained the weather indicators. To estimate extreme precipitation conditions, the ET-SPI regression included dummies variables as squared term for evapotranspiration rate, flood and drought. In addition, the effect of CO2 concentration was also analyzed.

The following results have been received. Firstly, the increasing temperature has the negative effect on yields for each crop. For example, rise in 1 degree Celsius declines maize yield by 8.3%. Secondly, the precipitation effect differs between LFAC (less favorable agricultural condition) and non-LFAC (more less favorable agricultural condition) countries. , the evapotranspiration rate has negative effect on yield for all studying crop. To make a prediction about future changes on crop yields, four scenarios were implemented (see Table 2). On the one hand, all of these storylines showed that temperature will increase within all four future scenarios which will lead to changes in precipitation, drought and floods in the region. On the other hand, each crop has different the range of the predicted effect of climate change on yield.

Finally, it is expected that future climate change will reduces yields of for all crops, with exception cassava. As found by Blank, under conditions of climate change crop yields is predicted to range between -19% and +6% for maize, between -38% and -13% for millet, between -47% to -7 % for sorghum [20]. One exception is represented by cassava. It is likely to be zero yield changes in 2100. However, the prediction in the case cassava must be interpreted with great extent of caution.

To consinder the third chosen paper by Schlenker and Lobell. Scholars examined the impact of climate change on yields of main five crop as millet, maize, groundnut, sorghum, cassava maize with using empirical model. Panel data was used in the research. Four specifications for modeling the impact of weather were implemented. There were (1) average weather, (2) quadratic in average weather, (3) a piecewise-linear function of temperatures captured by the two variables degree days 10–300C and degree days above 300C, (4) degree days categories: piecewise-linear functions within 5 ^{0}C intervals: [10 ^{0}C, 15 ^{0}C); [15 ^{0}C, 20 ^{0}C); [20 ^{0}C, 25 ^{0}C); [25 ^{0}C, 30 ^{0}C); [30 ^{0}C, 35 ^{0}C); [35 ^{0}C, ∞^0C). Based on the agricultural literature, researches used degree days as theoretical basis for crop growth. Therefore, scholars employed 16 climate change models with respect to the A1B scenario [14].

The researchers used the historic time series data from NCC between 1961 and 2002 and from CRU between 1961 and 2002, and therefore included predicted monthly daily maximum and minimum temperature changes into historic weather data. The results of empirical modeling showed that changes of temperature have the stronger impact on yields than changes of precipitation. It can be explained by two reasons. Firstly, "the marginal impact of one standard deviation in rainfall is smaller than the one standard deviation change in temperature [14]. Secondly, projections of temperatures increases for the 16 implemented climate models are larger relative to precipitation changes.

In the framework of three selected papers, it needs to consider limitations which researches faced, and draw particular attention source for climate data and crop data which were employed. The Table 3 depicts that in all three cases the crop data come from Food and Agriculture Organization (FAO) Corporate Statistical Database. Then, source of climate data mostly represents National Centre of Environment Prediction (NCEP), etc. For example, Ahmed et. al. used for the observation the National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAP) [19].

An important point is limitations that still exist in researches on the topic as: "the impact of climate change on crop yield". Firstly, adaptation strategies have not been taken into account. The adaptation is crucial element to mitigate impact of climate change. The adaptation to climate change will be discussed further. Secondly, there are some limitations related to dataset of Sun-Saharan African countries (see Table 3).

Table 3 – Summarized overview of existing limitations and implemented statistical datasets

Author	Limitation	Adaptation strategy	Source of climate data	Source of crop data
Ahmed et. al. (2015)	Adaptive potential of the farmes was not considered. Limitation connected tot he model calibration and verification.	No adaptation stategy	NCEP_NCAR	FAO data
Blanc (2012)	Crop managemant, weeds, pests, diseases, soil quility,	No adaptation strategies, mechanization has not been included	1) CRU TS 2.1 dataset 2) Mauna Loa Observatory 3) Data for four climate scenarios are derived from the TYN SC2.0 dataset.	FAO data
Schlenker and Lobell (2010)	Limited by crop dataset	No adaptation strategies	NCC, NCEP	FAO data

Source: Own illustrations.

Having studied three selected papers, it allows us to identify the following tendencies such as:

1. Econometric estimates suggest that the evaluation of the past event will keep the tendency in the future.
2. There are several explicative variables such as the crop yields, the area, and the CO_2 fertilization effect, the intensity of the warming scenario which have been examined and considered in the selected papers. However, fertilization is not considered as a key determinant of production in agriculture. So far, SSA region is not expected to increase significantly its usage. That means the level of fertilizer consumption will not be rise. Another key variable is crop variety selection that is not taken into account in a number of studies. So choice of SSA`s farmers is constrained due to poor variety of new seeds and seed supplies in SSA.
3. Scholars considered major staple crops (mostly cereal crops) in the context of Sub-Saharan African countries [14], [19], [20]. Note that cereal crops are important sources of getting calories and nutrition. These types of crops are mostly growing in rainfed lands in African region [21]. Hence, the most general crops examined in published studies related to the Sub-Saharan African region are millet, maize, cassava, sorghum.
4. Different types of crops have different amount of day in the context of the growing season. Crop sensitivity means that climate change has different response on different types of crops.
5. The different crops have different extents of sensitivity and vulnerability as a response to increasing temperature and warming, droughts, excessive precipitation. For example, Ahmed et. al. highlighted that maize is more sensitive to warming and drought, millet and sorghum are more sensitive to warming [19]. Blanc also found out that maize is more vulnerable to droughts. However, cassava is relatively a drought resistant plant, but vulnerable to redundant water. Furthermore, in countries with less favorable agricultural conditions millet is more sensitive to precipitation change compared to countries with more favorable agricultural conditions [20].
6. According to Ahmed et. al., spatial variability in crop productivity is one of the crucial factors that should be taken into consideration to emphasize the impact of climate change on regional agriculture [19].
7. Due to cassava is a root crop, it is not simply empirically to match data of weather in the framework of growing season to a certain yield.

4. Conclusions

In conclusion, the study of the papers on the topic "the impact of climate change on crop yields" shows that climate change is expected to be additional stress to economies of Sub-Saharan African countries in the future. As discussed, agriculture in SSA region is the most vulnerable sector to climate change conditioned by natural factors such as rainfed lands, water scarcity; also limited economic funds and institutional potential to perform adaptation. One could suggest that the impact of adverse climate change on crop yields and agriculture as whole are associated with uncertainties. To decline the climate change impact on crop yield in the future, it needs to make relevant predictions to timely implement adaptation strategies. Having examined the chosen papers, the main finding is that changes in temperature and precipitation lead to reductions of crop productivity through different physiological mechanisms of plants. Thus, international academic society should continue to investigate these issues and try to find solution to build resilience of agriculture to climate change.

Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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