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Yam Production-Related Agro-climatological Risks and Yam Yield Modeling in Côte d'Ivoire: A Review

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Abstract

In this paper, we present a review of the agro-climatological-related risk of yam production and models developed for yam yield prediction in Côte d'Ivoire. Four official national platforms (Ministry of Agriculture and Rural Development (MINADER), National Center for Agricultural Research (CNRA), National Agency for Rural Development Support (ANADER), Airport, Aeronautical and Meteorological Exploitation and Development Company (SODEXAM)) and six scientific search engines were investigated in this study including Theses.fr, African Journal Online, Science Direct, Google Scholar, WorldCat and Semantic Scholar. Using the boolean parameters "AND", "OR" and "()" to facilitate and direct our search, we were able to define four key phrases comprising the topic words that were used in the search. Exclusion and inclusion criteria for the selection of documents were also defined in advance, as well as the criteria for reviewing and extracting information from selected documents. The results showed that no work in the field of agro-climatological risks related to yam production and yam yield modeling in Côte d'Ivoire was available on these online research platforms at the time of this literature review. However, other studies similar to the scope of this review on yam exist in several West African countries, particularly Ghana, Benin and Nigeria, and also in the Caribbean. These studies use simulation models such as the Approach for Land Use Sustainability (SALUS) model, the Environmental Policy Integrated Climate (EPIC) model and the Cropping Systems Simulation (CROPSYST) model for growth, yield modeling and the influence of climatic parameters on yam. In addition to these models, artificial intelligence through machine learning models was also seen in this review as an excellent tool for yield prediction for several crops including yams.

Keywords: yam production, agro-climatological risks, yam yield modeling, literature review, Côte d'Ivoire

1. Introduction

In recent years, the African continent has experienced longer and more intense heat waves than in the last two decades of the 20th century (Engdaw et al., 2022). In addition, 50% of regional climate projections suggest that these heat waves, which are unusual in current climatic conditions, will be more regular by 2040 or even more severe under the RCP8.5 scenario (Faye, Camara, Diarra, Mboup, & Noblet, 2019). Regarding rainfall, many uncertainties remain: A decrease in rainfall is expected in the Western Sahel while the Eastern Sahel is expected to experience an increase in rainfall. Note that, under the worst-case climate change scenario, a reduction in mean yield of 13% is projected in West Africa (Sultan et al., 2015). Therefore, agriculture is one of the most sectors which are vulnerable to global weather and climate change. In Sub-Saharan Africa (SSA) it is the main occupation and source of income for most of the populations and, therefore, has a great influence on regional food security (Sultan et al., 2013; World Bank Group, 2019). However, the region faces food shortages almost every year due to crop failure or low crop yields (Cedric et al., 2022; Waongo, 2015). According to these authors (FAO, 2015, 2017; Raes et al., 2018), the use of adapted varieties or breeds, with different environmental optima and/or broader environmental tolerances, including currently neglected crops, also considering that increased diversification of varieties or crops is a way to hedge against the risk of individual crop failure. Among these crops' failure, there is the yam which is the second most important root/tuber crop in Africa after cassava (Lebot & Dulloo, 2021). Yams (*Dioscorea* spp.) are extremely important to food security because of their excellent storage properties; they can be stored for four to six months without refrigeration and provides an important food safety net between growing seasons. They are a staple food for millions of people in tropical countries and provide pharmacologically active compounds for traditional medicine and the pharmaceutical industry (Adifon et al., 2019; Andres et al., 2016; Neina, 2021). Yams are grown in about 50 tropical countries, not all of which provide their annual production statistics to the United Nations Food and Agriculture Organization. Annual world production is about 72 million tonnes of fresh tubers. More than 98% of this production is grown in Africa, with only four countries (Nigeria, Côte d'Ivoire, Ghana and Benin) accounting for 93% of this production (Lebot & Dulloo, 2021). Particularly, Yams are widely grown in Côte d'Ivoire, and among food crops, yam is the most cultivated (BCEAO, 2017; Diarrassouba, 2019; MINADER, 2017). It is therefore a crop that has a choice place in the Ivorian economy and food and nutritional security. The landrace varieties *Kponan*, *Krengle*, and *Djate*, are in high demand, as are the improved varieties TDA, Mao and C20. The latter have demonstrated good productivity, disease resistance and drought tolerance.(Adifon et al., 2019; Kouakou et al., 2019; Michel & Apata, 2017). Despite all these assets, yam production is facing challenges due to several issues. Planting and harvesting are labour-intensive, yield and postharvest durability vary significantly with soil quality and climactic factors, decreasing soil quality and mounting pest pressures, rotting of seedlings in the mound due to high surface temperatures, the false start of the rainy season and the failure to update agricultural calendars according to rainfall variability are among the causes faced by farmers and the yam sector in Côte d'Ivoire (Anogbro, 2015; Frossard et al., 2017; Kouakou et al., 2019; World Bank Group, 2019). So, it requires continuous monitoring to improve crop yields (Kosamkar & Kulkarni, 2019). Given the changing climate, predicting scenarios and crop yield based on models will help increase production, forecast the growing season, take adaptive measures and allow farmers to be more resilient (Fayaz et al., 2021; Kosamkar & Kulkarni, 2019; Malhi et al., 2021). Note that, at the national level in the literature about yam cropping, almost all the studies done by researchers are in biology, genetics, physiology and the marketing of yam area. Some climate variabilities are also studied, highlighting the impacts of the latter (Anogbro, 2015; Doumbia et al., 2006; Kouakou et al., 2019; Valerie, 2012). For this reason. in this paper, we present a review of the agro-climatological-related risk of yam production and models developed for yam yield prediction in Côte d'Ivoire. Crop models are an essential tool for studying the impact and potential adaptation options in root and tuber production. A crop model consists of mathematical equations that describe the development and growth of the crop over time, based on environmental factors (Cedric et al., 2022; Fayaz et al., 2021; Raymundo et al., 2014). Crop models use crop characteristics, climate data and soil characteristics to simulate crop responses to management practices and various environmental conditions. Crop models can be used to anticipate the effects of climate change on root and tuber production (Degila et al., 2023; Raymundo et al., 2014). In this study, we will evaluate the existing models that have served as a study of yam in Côte d'Ivoire through scientific search engines, online documentary databases and national reports. The general differences, their structures, similarities, limitations and applications in the field of climate change and research gaps have been discussed.

2. Material and Methods

2.1 Presentation of Côte d'Ivoire

Côte d'Ivoire is located between Longitudes 2°30′ and 8°30′ W and Latitudes 4°30′ and 10°30′ N with an area of 322 462 km^2, covering about 1% of the African continent. It is part of West African countries sharing borders with Liberia and Guinea to the West, Mali and Burkina-Faso to the North and Ghana to the East part (Figure 1). The South part of the country is covered by the Atlantic Ocean with a 550 km long coastline (Kouame et al., 2020). The central and coastal areas each have four seasons: April to mid-July: a long rainy season, with frequent rainfall and numerous thunderstorms; mid-July to September: a small dry season, the sky can remain overcast; September to November: a short rainy season, with some light rainfall; December to March: high dry season. The northern zone has two seasons: the period from June to September is the rainy season and the period from October to May corresponds to the great dry season (Kouame, 2021; Kouame et al., 2020).

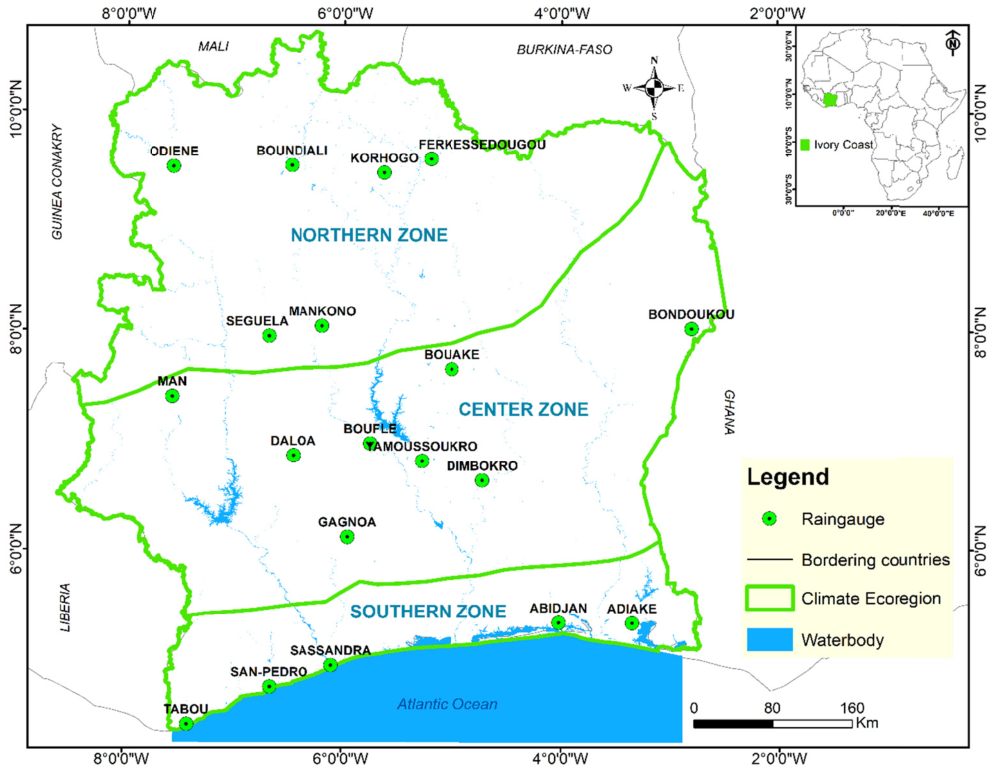

Figure 1. Distribution of the rain gauges and climatic division depending on rainfall patterns in Côte d'Ivoire

Source: Kouame et al. (2020).

2.2 Research Methodology

This study was carried out in the framework of a literature review of existing studies, systematic reflection, and scientific journals/reports to highlight the approaches already done and available results relating to yam production-related risks and yam yield modeling in Côte d'Ivoire. We searched tools, methods, data used and results reported in the literature. Several documents, such as articles, national reports and peer reviews, were considered in this study. In order to achieve this, we referred to Boolean terms (Dahan & Kasei, 2022; Kohl et al., 2018; Ouattara et al., 2023; Tran et al., 2023). Boolean operators (sometimes called Boolean terms or commands) connect the keywords to create a logical phrase that the database can understand. This involves telling the database to look for multiple terms or concepts at once, which makes the search more precise (Kohl et al., 2018; Pušnik et al., 2022; Snyder, 2019). The Boolean operators used in this research are "AND", "OR" and "( )" (Table 1).

Table 1. Boolean operators: "AND", "OR" and "( )"

Boolean operators	What it Does
AND	Find items that use **BOTH** keywords.
OR	Find items that use **EITHER** of the keywords.
Brackets ( )	**GROUP** multiple search strings and **SET PRIORITIES**

For the purpose to exploit the boolean operators, and search for the necessary data to complete this study, four (4) official websites of Ivorian institutions in charge of agriculture for some and climate for others (**Table 2**) and six (6) scientific search engines for online documentation (**Table 3**) were defined and consulted individually. This makes a total of ten (10) information sources defined for this review.

Table 2. Official websites of Ivorian institutions

	Institutions names	Websites
1	Ministry of Agriculture and Rural Development (MINADER)	https://www.agriculture.gouv.ci/
2	National Center for Agricultural Research (CNRA)	https://cnra.ci/
3	National Agency for Rural Development Support (ANADER)	http://www.anader.ci/
4	Airport, Aeronautical and Meteorological Exploitation and Development Company (SODEXAM)	https://www.sodexam.com/

Table 3. Scientific search engines

	Platforms	Website*	Purpose and country	Launch year
1	Thesis search engines	https://www.theses.fr/	It is a search engine to find French doctoral theses. Based in French	Jul. 2011
2	African Journals Online	https://www.ajol.info/index.php/ajol	Provides access to African-published research, and increases worldwide knowledge of indigenous scholarship. Includes 38 African countries including Côte d'Ivoire	1998
3	Science Direct	https://www.sciencedirect.com/	Provides access to a large bibliographic database of scientific and medical publications of the Dutch publisher Elsevier. It hosts over 18 million pieces of content. Based in Netherlands	Mar. 1997
4	Google Scholars	https://scholar.google.com/	Google Scholar is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines. Based in USA	Nov. 2004
5	World Catalogue	https://www.worldcat.org/	WorldCat is a union catalogue that itemizes the collections of tens of thousands of institutions (mostly libraries), in many countries, that are current or past members of the OCLC (USA nonprofit cooperative organization) global cooperative. Based in USA	Jan. 1998
6	Semantic Scholar	https://www.semanticscholar.org/	Semantic Scholar is an artificial intelligence-powered research tool for scientific literature developed at the Allen Institute for Artificial Intelligence (AI). Based in USA	Nov. 2015

Note. *: These information sources can be found on the above websites.

2.3 Document Search

This phase consisted of a search strategy for the documentation. The search strategy allowed us to define an appropriate search string based on the relevant databases identified and defined in the previous Tables 2 and 3. The number of articles included in the final analysis was influenced by the search criteria defined in Table 4. Furthermore, the definition of the search string was based on the topic terminologies. The search string is listed focusing mainly on "Yam production-related agro-climatological risks" and "Yam yield modeling in Côte d'Ivoire" with the addition of Boolean operators (Tables 5 and 6). The search terms were performed separately or in limited combinations that took into account the requirements or limitations of the database used (Mengist et al., 2020). In these databases, publications that were not downloaded for further study were discarded. The articles were peer-reviewed journals from the seven data sources and the literature searches were finalized on 19 May 20023. The search was conducted in these different internationally recognized databases to collect relevant information from the publications (Gonçalves et al., 2018). These are all international databases of peer-reviewed publications from around the world (Gonçalves et al., 2018; Mengist et al., 2020). Besides, the size and types of databases used to search for publications helped determine the size of the sample drawn for examination. Note that the research on the national platforms was done both in English and French, the latter being the country's (Côte d'Ivoire) official language.

Table 4. Selection of literature using inclusion and exclusion criteria

Criteria	Decision
When the predefined keywords exist as a whole or at least in the title, keywords or abstract section of the paper.	Inclusion
The paper was published in a scientific peer-reviewed journal.	Inclusion
The paper should be written in the English or French language.	Inclusion
Studies presenting evidence on crop modeling/climate impact studies on yam.	Inclusion
When the articles address at least one agro-climatological indicator.	Inclusion
Papers that are duplicated within the document search engines.	Exclusion
Papers that are not accessible, review papers and meta-data.	Exclusion
Papers that are not primary/original research.	Exclusion
Papers published before 1998.	Exclusion

Source: Adapted from Mengist et al. (2020).

Table 5. The search terms used and the total number of publications from the country databases

Databases	Databases Searching string and searching terms		No. of papers	Date of acquisition
MINADER	Main searching terms	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Secondary searching terms	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Tertiary searching terms	Yam production-related agro-climatological risks (Côte d'Ivoire)	00	5/19/2023
	Fourth searching terms	yam yield modeling (Côte d'Ivoire)	00	5/19/2023
CNRA	Main searching terms	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Secondary searching terms	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Tertiary searching terms	Yam production-related agro-climatological risks (Côte d'Ivoire)	00	5/19/2023
	Fourth searching terms	yam yield modeling (in Côte d'Ivoire)	00	5/19/2023
ANADER	Main searching terms	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Secondary searching terms	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Tertiary searching terms	Yam production-related agro-climatological risks (Côte d'Ivoire)	00	5/19/2023
	Fourth searching terms	yam yield modeling (in Côte d'Ivoire)	00	5/19/2023
SODEXAM	Main searching terms	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Secondary searching terms	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	00	5/19/2023
	Tertiary searching terms	Yam production-related agro-climatological risks (Côte d'Ivoire)	00	5/19/2023
	Fourth searching terms	yam yield modeling (in Côte d'Ivoire)	00	5/19/2023

Table 6. The search terms used and the total number of publications from scientific search engines

Databases	Database searching string and searching terms		Searching matches	No. of papers	Date of acquisition
Thesis search engine	Main	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire		00	5/21/2023
	Secondary	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire		00	5/21/2023
	Tertiary	Yam production-related agro-climatological risks (Côte d'Ivoire)		00	5/21/2023
	Fourth	Yam yield modeling (in Côte d'Ivoire)	Searching terms don't match any title. Just one keyword	11	5/21/2023
African Journals Online	Main	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire	Searching terms don't match any title. Just some keywords	16	5/19/2023
	Secondary	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	Searching terms don't match any title. Just some keywords	36	5/19/2023
	Tertiary	Yam production-related agro-climatological risks (Côte d'Ivoire)	Searching terms don't match any title. Just some keywords	42	5/19/2023
	Fourth	Yam yield modeling (in Côte d'Ivoire)	Searching terms don't match any title. Just some keywords	76	5/19/2023
Science Direct	Main	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire		00	5/21/2023
	Secondary	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	Searching terms don't match any title. Just some keywords	298	5/21/2023
	Tertiary	Yam production-related agro-climatological risks (Côte d'Ivoire)		00	5/21/2023
	Fourth	Yam yield modeling (in Côte d'Ivoire)	Searching terms don't match any title. Just some keywords	268	5/21/2023
Google Scholar	Main	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire		00	5/20/2023
	Secondary	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire		00	5/20/2023
	Tertiary	Yam production-related agro-climatological risks (Côte d'Ivoire)		00	5/20/2023
	Fourth	Yam yield modeling (in Côte d'Ivoire)	Searching terms don't match any title. Just some keywords	8,790	5/20/2023
World Catalogue	Main	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire		00	5/20/2023
	Secondary	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire	Searching terms don't match any title, any keyword	02	5/20/2023
	Tertiary	Yam production-related agro-climatological risks (Côte d'Ivoire)		00	5/20/2023
	Fourth	Yam yield modeling (in Côte d'Ivoire)	Searching terms don't match any title, any keyword	02	5/20/2023
Semantic Scholar	Main	Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire		00	5/20/2023
	Secondary	Yam production-related agro-climatological risks OR yam yield modeling in Côte d'Ivoire		00	5/20/2023
	Tertiary	Yam production-related agro-climatological risks (Côte d'Ivoire)	Searching terms match only some keywords	05	5/20/2023
	Fourth	Yam yield modeling (in Côte d'Ivoire)	Searching terms don't match any title. Just some keywords	126	5/20/2023

3. Documents Analysis

The information extracted from the documents was analyzed qualitatively based on different criteria and categories (Table 7). This objective analysis was done to ensure the viability and authenticity of the data source used in the papers collected (Dahan & Kasei, 2022; Gonçalves et al., 2018; Manikas et al., 2023; Mengist et al., 2020; Snyder, 2019). After a sufficiently thorough reading of the various documents, the information relevant to this study was extracted according to the criteria and categories captured in Table 6 below.

Table 7. The criteria used for extracting information from the selected papers

No	Criteria	Categories considered	Justification
1	Document types	Official papers/articles/reports/thesis	from one of the ten (10) sources defined for this review is considered
2	Year of publication	Between 1998 and Mai 2023	The year in which the oldest journal goes online is considered
3	Study area	Country	-
4	Types of data sources	Primary data	Data derived from sampling in the field (*e.g.*, field data, surveys, interviews or census data)
		Secondary data	Data not verified in the field (*e.g.*, remote-sensed data, a bibliography, modeling, socioeconomic data)
		Mixed data	Mixed both above sources
5	Methods	Cultivar and soils types; Climate indices; statistics relationships; models used.	Incorporate existing knowledge to link with Yam models, climate models and Yam production-related agro-climatological risks.
6	Mode of assessment	Qualification, quantification, or both	Expressing climate and agriculture values with verbal terms or using numbers mathematics expressions or both
7	Difficulties mentioned	Methodological	Uncertainties on the result due to the application of the unclear or less developed method; Uncertainties linked with lack of conceptual clarity.
		Data analysis	Data analysis skills and the choice of suitable tools can challenge the work.
		Lack of model validation	Most crop modeling studies lack to verify the results using model validation.

4. Results and Discussion

4.1 Review of the Search Performed

4.1.1 National Platforms Search Engines

On the National platforms, none of the four (4) revealed a single trace of documents or research available. This could mean that no studies in this or a related field have been carried out and are available. It could also mean that the documents of the works are published elsewhere either than the platform or that the works are kept in hard copies in the libraries of these structures.

4.1.2 Theses.fr Search Engine

At the level of the Theses.fr platform: only eleven (11) documents were found in all the searches. It is the fourth searching term [*yam yield modeling* (*Côte d'Ivoire*)] that allowed us to have this result. The search was carried out by selecting all the possible search options available on the website, including 'defended theses only' and 'defended and online theses', and the year, which by default is defined as the broadest possible on the website 'before 2013 to 2023'. Thus, none of these 11 documents were selected according to the inclusion and exclusion criteria established beforehand. Indeed, the search terms do not appear at any level in the titles of the documents nor the keywords, but it should be noted that this French PhD platform provides a wide range of related fields in addition to what is requested.

4.1.3 AJOL Search Engine

On the AJOL databases, 181 papers were found across all four search terms. Among these documents, the most relevant ones deal with climate change for some and yam production for others, but in other countries. None of these papers address the issue of yam yield modeling in Côte d'Ivoire, or elsewhere. In fact, AJOL displays from its database the documents available according to the search terms used, including those that have nothing to do with the topic. As I read on, I realized that AJOL relies on the search terms found in the abstract of certain documents to suggest search results. This is why we had 170 documents and none of them were useful for our intended purpose.

4.1.4 Science Direct Search Engine

The research was successful in that we obtained five hundred and sixty-six (566) results from all four searches. With Science Direct, we were able to detect some documents that deal with our topic elsewhere in other countries. We have kept these documents for further analysis. It should be noted that synonyms for certain keywords such as 'modeling' were found in the form of 'simulation'. Moreover, we were able to find these words in the same document: '*Simulating*', '*yield*', '*yam*' and also these words: '*Modeling*', '*yam*', '*yield*' in the same document. Some of these works whose association with these keywords were carried out in West African countries like Benin Republic and Ghana. In these documents, after analysis, it can be seen that some models have been used to effectively simulate yam yield. We note: Environmental Policy Integrated Climate (EPIC) model (Srivastava & Gaiser, 2010) and the Systematic Approach for Land Use Sustainability (SALUS) model (Liu et al., 2021).

4.1.5 Google Scholar Search Engine

On Google Scholar, no document was found after the three first search terms. In the last search terms, we got eight thousand seven hundred and ninety (8,790) results. All the key works were found but not in the same document. We applied three successive filters to select the most relevant ones using quotation marks (" "). The first was: [*yam yield* "*modeling*" (*Côte d'Ivoire*)], the second was: [*yam* "*yield modeling*" (*Côte d'Ivoire*)] and finally, the third was: ["*yam yield modeling*" (*Côte d'Ivoire*)]. Successively, the result went from 8,790 to 2,390 then to 08 and then to 00. One of the documents in which we can find keywords that Google Scholar provided is entitled: Simulating cocoa production: «A review of modeling approaches and gaps. But unfortunately, it does not address the subject of yam. It should be noted that Google Scholar is one of the most widely used scientific search engines worldwide and is accessible to all researchers for the promotion and enhancement of research. Therefore, the absence of a relevant document in Google Scholar implies If despite this fact, no relevant document has been found, there is reason to believe that the work has not yet been studied in Côte d'Ivoire.

4.1.6 WorldCat Search Engine

On WorldCat, the world's largest library catalogue, our searches yielded four (4) results in all especially two in the second and two in the fourth search terms. However, after analysis, there were the same two documents found in each search. These documents do not contain any of the keywords of our research, neither in the titles nor in the abstract keywords.

4.1.7 Semantic Scholar Search Engine

On Semantic Scholar, our searches yielded a hundred and thirty-one (131) results in all search terms. It includes all the keywords but all of them were found in the fourth search individually in different documents that do not necessarily deal with yams. An example of a topic: "Potential Impact of Climate Change on the Sediment Fluxes of a Watershed in West Africa". The other is: "Modeling greenhouse gas emissions of cocoa production in the Republic of Côte d'Ivoire". You understand that these are the most relevant of the 126 documents but are not useful because they do not address the cases we are looking for. However, Semantic Scholar is a powerful search engine with over 200 million papers from all fields of science. The best part is that it is free to access and all papers are open access to download with all possible metadata with redirections to other topics of interest depending on the papers downloaded.

Below is a screenshot of the search performed in each scientific search engine with the main search term which is: [*Yam production-related agro-climatological risks AND yam yield modeling in Côte d'Ivoire*] (Figure 2).

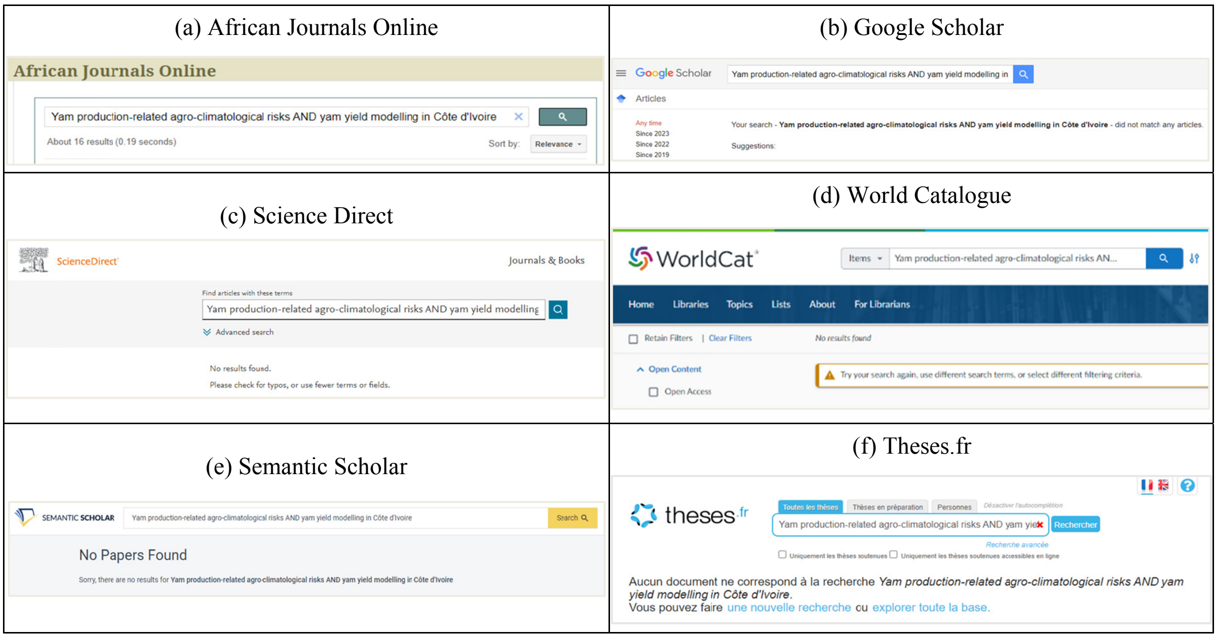

Figure 2. An example of a screenshot of each research performed using the main search terms in scientific search engines

4.2 Outcomes Using Inclusion and Exclusion Criteria

By applying the inclusion and exclusion criteria, papers that fulfill the inclusion criteria were selected for further investigation and content assessments. Unfortunately, no papers dealing with the subject we are discussing have been selected for Côte d'Ivoire. The predefined literature inclusion and exclusion criteria to achieve this review work were presented in Table 4. It is important to add that papers like grey literature, extended abstracts, presentations, keynotes, and research work that is not original and duplications were omitted. Figure 3 shows the flowchart diagram of our research according to the exclusion and inclusion criteria.

4.3 Related Work

The related work section focuses on literature reviews involving the eligibility documents. As no studies in our field of research have been carried out in Côte d'Ivoire, we have turned to eligibility documents for further analysis to find out more about what is being done at this level in the West African sub-region or elsewhere. Indeed, related works have been done in Benin Republic, Nigeria and Ghana according to the eligibility papers (08 documents) in Figure 3. These countries are all Sub-Saharan West African coastal countries with the same hot and humid tropical climate. We have therefore used the results of this research to find out exactly what has been done and to explore the possibilities of transferring technology from these findings to the local level in Côte d'Ivoire following Table 7 categories and criteria for the analysis. Crop yield modeling is one of the most important elements of agricultural decision-making today. Crop system models are therefore valuable tools to inform agronomic decisions and advance research. The prediction accuracy of simulation models is one of the most vital components in yield modeling.

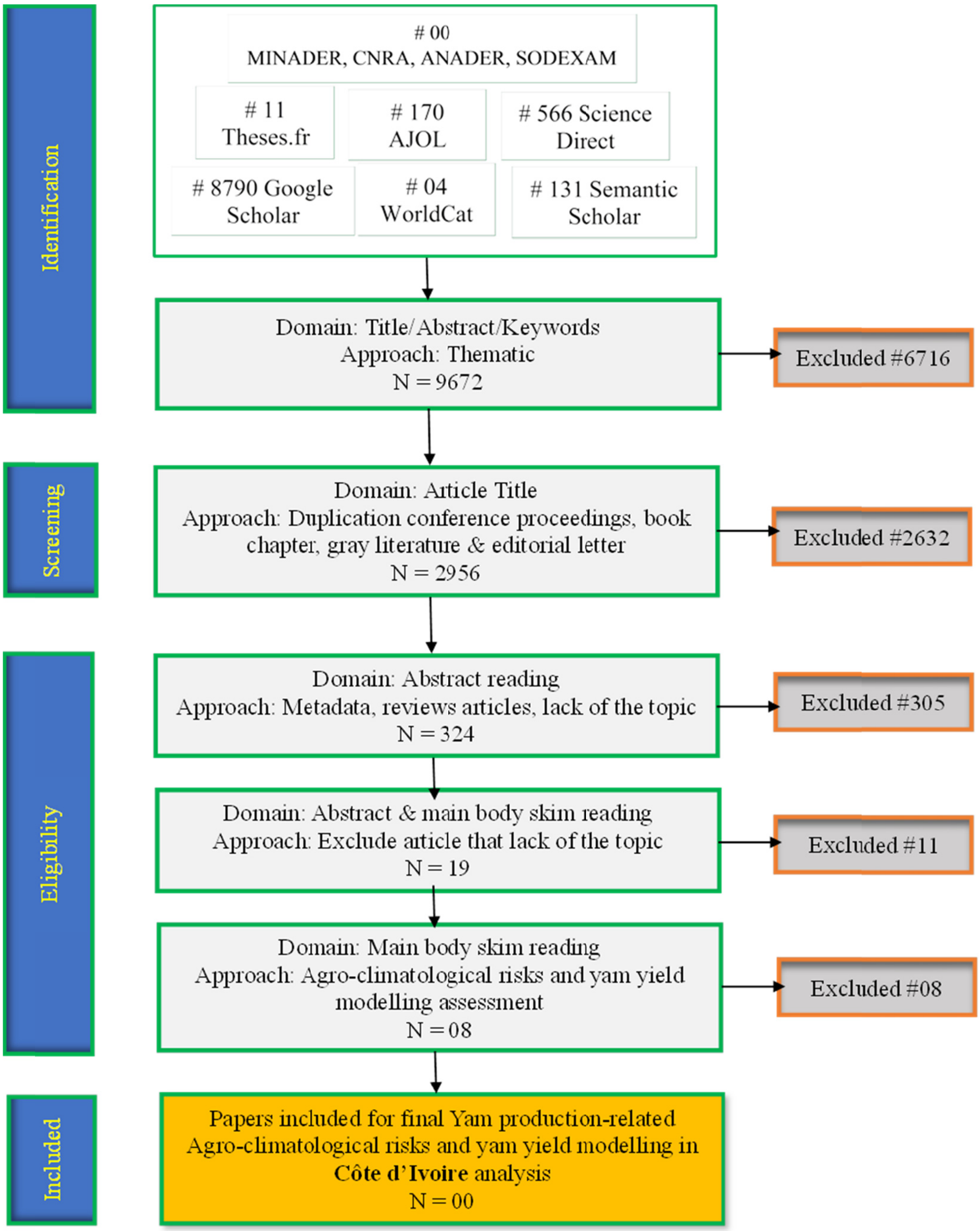

Figure 3. Flowchart diagram for databases search of documentation for reviews and the results found

Source: Adapted from Mengist et al. (2020).

The basic operating mode of crop models requires input data such as soil, climate, plant and management which is used by crop simulation model for predicting the crop yield (Figure 4) and describe the process of growth and developmental stages of crops (Dzotsi et al., 2013; Kosamkar & Kulkarni, 2019; Srivastava et al., 2012).

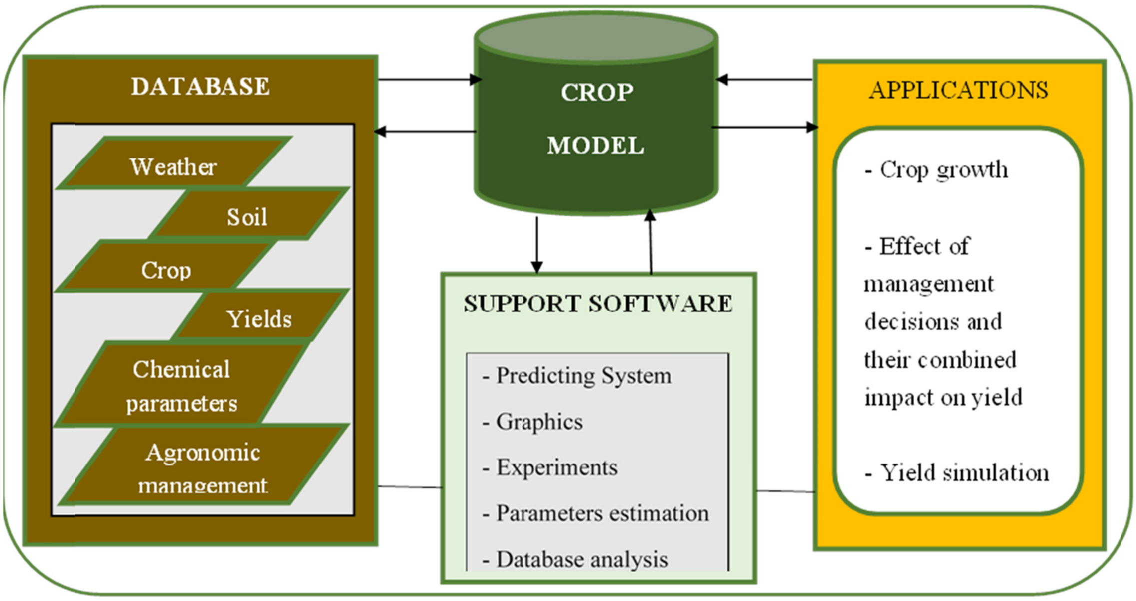

Figure 4. Crop modeling operating system

Source: Adapted from (Dzotsi et al., 2013; Jones et al., 2003; Srivastava et al., 2012).

4.3.1 Yam Yield Modeling Approaches

In their work, these authors (Liu et al., 2021; Marcos et al., 2011; Srivastava et al., 2012; Srivastava & Gaiser, 2010) studied yam yield modeling, water yam (*Dioscorea alata* L.) growth and the prediction of yam productivity under different agronomic management. Table 8 below summarizes the details of their modeling approaches. Several yam-adapted crop models and machine learning techniques have been used for yam modeling across Africa and the Caribbean (French Antilles).

Table 8. Summary of the approaches to Yam yield modeling

Study area/ Models used/ Authors and year	Inputs data	Parameterization/ Statistical analysis/ Model evaluation	Outputs modules
Ghana/ Approach for Land Use Sustainability (SALUS) model/ (Liu et al., 2021)	- Yam parameters for the model were based on reported values in the literature and the calibration processes; - Crop coefficients and management (planting dates, fertilizer, irrigation water, and tillage); - Soil data (organic C, total N, bulk density, clay, and silt) derived from the Africa Soil Information Service (AfSIS) database includes soil layer parameters The gridded soil profile resolutions were 1 km and 250 m; - Weather data including min-max temperature, precipitation, and solar radiation from the gridded 0.5◦-resolution POWER dataset and also from stations at the two locations of the study.	- Use of field observations and compare the simulated phenology and biomass (both tuber yield and aboveground biomass) to the field observations from two different locations to parameterize the SALUS-Yam model; - Root mean square of deviation (RMSD) and mean absolute percentage error (MAPE) used to evaluate SALUS-Yam model accuracy; - Outputs modules evaluations were based on comparisons between observed and simulated data applied to the crop model.	- Soil Organic Carbon (SOC) and yield response under the different agro-ecological zone soil types, and changes in nutrients and water; - Simulation of yam phenology and biomass response to N and P fertilizer; - Two major sources of uncertainty were observed: soil and weather inputs.
Benin Republic/ Environmental Policy Integrated Climate (EPIC) model/ (Srivastava et al., 2012; Srivastava & Gaiser, 2010)	- Data for the model calibration including rainfall distribution, crop characteristics (aboveground biomass, tuber yield, LAI, etc.) and soil properties (moisture retention properties, chemical composition, etc.) were obtained on-farm trials at Dogue village; - Crops parameters values were derived from four sources: experiments, cassava parameter file from EPIC (version 3060), literature and the adjusted value.	- The mean residual error (ME) and the mean absolute error (MR) were used to compare observed data and simulated values; - The EPIC model performance was evaluated by comparing the simulations of 2 years' worth of yam yields with an experiment from Dogue village and by determining the coefficient between the observed and simulated yield of yam.	- Simulation of yam growth and the effect of fertilizer on yam yield; - Yam (*D. alata*) growing conditions in sub-humid tropical savannah areas.
Guadeloupe/ Cropping Systems Simulation (CropSyst) model/ (Marcos et al., 2011)	- Two independent data sets from field experiments under non-limiting conditions for water and nutrients and over a wide range of planting dates and photoperiods including Mean temperature (◦C), Mean global radiation (MJ m^2 d^{-1}), Mean photoperiod (h), Planting date and years of the experiment; - Rainfall data (annual rainfall for each year) from the Experimental Station of Duclos; Soil data, yam yield (variety Lupias); - 200g of fresh biomass was used for the yam planting.	- Calibration of the model and test of the model were based on comparisons between observed and simulated data from Experiment 1 and Experiment 2; - Determination coefficient (R^2) and Root Mean Square Error (RMSE) were used to determine the best fit of parametrization of the model and to evaluate the two Experiments conducted.	- Change in the Radiation Use Efficiency (RUE) as a function of the planting date; - RUE effect on yam growth and yields; - Yam development and growth; - Vegetative and Tuberisation phase, Total biomass and Yam yield from the two Experiments (1 and 2) were compared.
West African countries/ Machine learning, models-based decision tree/ (Cedric et al., 2022)	- Crop yield, annual rainfall, temperature, pesticides and chemical data from 1990 to 2020 from nine West African countries collected from the Food and Agriculture Organization for the United Nations and the Climate Knowledge Portal World Bank; - Analysis parameters: Yield (kg/ha), Temperature (K), Pesticide (t), Rainfall (mm), NO_2 (1018 µg).	- Crops Multivariate Logistic Regression (CMLR), Decision tree, and k-Nearest neighbor algorithm as machine learning algorithms for modeling processing; - Pearson Correlation between features (NO_2, Temperature, Rainfall, Pesticide, Yields, Years); - Use three metrics to evaluate the models: Determination coefficient (R^2), Mean Absolute Error (MAE) and the Run-Time of each model.	- Illustrations of the main parameters influencing the six crop yields: rice, maize, cassava, cotton, yams, and bananas; - Prediction of each crop yield.

4.3.2 Impact of Climate Change on Yam Yield

Climate change has the potential to significantly impact yam production through soil degradation, increasing the incidence of pests, and diseases and creating yam tuber beetle, and changes in rainfall patterns. As yam is a rainfed crop, hence, changes in rainfall patterns can significantly impact its production. According to a study by the World Bank Group (2019), these effects due to climate change lead to decreased yam yields in Côte d'Ivoire. Also, sorting out issues relating to yam production in Nigeria, authors conducted a study forecasting the effect of climate variability on yam yield in rainforest and guinea savannah agro-ecological zone of the country. They used secondary data sources including the climatic data variables, yam area cultivated and yam output in their study (Adeleke Aturamu et al., 2021). The results of the study showed that rainfall and temperature are changing over time and unpredictable. Using the Representative Concentration Pathway (RCP), yam yield for 2050 was predicted to be 0.34mmt/ha and 0.21 mmt/ha under RCP 4.5 and RCP 8.5 scenarios respectively. Over time (2030, 2040 and 2050) in the rainforest Agro-ecological zone (AEZ), yam yield is expected to be negative under both RCP scenarios (RCP 4.5 and RCP 8.5) (Table 10). Furthermore, in the savannah zone of West Africa, Srivastava et al. (2012) addressed the global climate change impacts on tuber crops by using a simulation approach to assess the long-term regional-scale changes in yam production under A1B and B1 IPCC SRES scenarios. They did not stop only that, better, they were able to examine the vulnerability of yam to climate change in conjunction with the soil conditions. The methodology, data and approaches used are recorded in Table 8. Concerning their findings, they concluded that the impact of climate change under the A1B IPCC SERES scenario on yam production is significant and will be protuberant in the 2040s. Concerning the soil type, S1 (Ferruginous soils impoverished without concretions) seems to be the most sensitive to climate change followed by S2 (Ferralitic soils) and S3 (Raw mineral soils) (Srivastava et al., 2012). Still on the effects of climate variability on yam production, a study was conducted in the Nothern part of the Benin Republic by Adifon et al. (2020). Their study shows that the agro-climatic stress index (ASI) and the annual rainfall are the main climatic factors which determine the yield of yam in the various growing areas in Benin. He was also able, through a field survey among yam farmers, to gather their perceptions of yam production conditions and the challenges they face. The survey revealed that yam farmers are unanimous about the influence of the variability of climate parameters on the growth and production of yams (Adifon et al., 2020). The methodological approach he used is described in Table 9.

Table 9. Summary of the approaches to climate change on yam production

Data description/sources	Methods/Approaches/Period of the study	Country/Area/ References
Data are from secondary sources: - Yam area cultivated; - Climate data: CRU, ECMWF, ERA-Interim; - Validation data: station-based observations; - Historic climate datasets (Daily data for 120 years); - Future climate data: RCP 4.5 and RCP 8.5.	- Surveys using multistage sampling and random techniques in the selection of communities. - Establishing empirical climate variability over time from 1900 to 2019 (118 years); - Analyze a historic climate data period (1901-2019) with thirty-year (30) subdivisions made to four (4) non-overlapping epochal climate periods; - Future climate data period (2020-2050); - Statistical methods: Probability Density Function (PDF), trend analysis and change points analysis for establishing climate variabilities over time.	Guinea/ Savannah and Agro-ecological zone of Nigeria/ (Adeleke Aturamu et al., 2021)
Data are from secondary sources: - Slope inclination and length, topographical information; - Regional climate model outputs (GCM ECHAM5 downscaled) with A1B scenario; - REMO model and the A1B scenario output of the GCM HADC3Q0 downscaled; - The RCMs SMHIRCA and HADRM3P with the A1B scenario output; - Regional soil database from the soil association map; - Regional cropland database with the EPIC crop growth simulation model.	- Comparison of EPIC output for baseline (1961-2000) and time horizon (2001-2050); - Combines the agro-ecosystem model EPIC with the hydrological model SWAT (Soil Water Assessment Tool); - Changes in temperature and precipitation and the response of soil types to these changes; - Subdivision of the catchment into agronomic response units of variable size which constitute the spatial simulation units (LUSAC = Land Use-Soil Association-Climate units); - The LUSAC represent an area with similar climate conditions, soil characteristics and a representative crop and soil management; - Yield of yam had been calculated within each LUSAC for the period of 40 years (1961-2000) and 50 years (2001-2050). - Validation of the model: A total of four climate scenarios based on A1B and B1 emission scenarios with different RCM output has been simulated: The baseline period with the simulated historical data (1961-2000) and the time horizon (2001-2050) under IPCC SERES A1B and B1 scenario conditions. The CO_2 concentration was set at 350 ppmv for the baseline simulations.	Savanna zone of West Africa/ Particularly in the Upper Ouémé basin/ (Srivastava et al., 2012)
Data are from primary sources: - Daily climate data: temperatures, precipitation, potential evapotranspiration, relative humidity and insolation collected from the METEO-Benin; - Field data (Survey); - Yam yield data.	- Daily climate data period (1981-2016); - Survey from 351 producers to collect their perceptions about climate variability on the yams production; - Descriptive statistics analysis of the field data; - Principal component analysis (PCA) to determine the local perceptions of the effect of climatic parameters on yam production; - Trend analyses, Lamb index calculations and the agro-climatic stress index (ASI) using the climate data to determine the climate variability; - Yam yields by zone were calculated based on data collected from farmers and the yam areas cultivated by year; - The econometric approach based on ordinary least squares (OLS) has been adopted in order to identify among the climatic parameters those that best explain the yield of fresh yam tubers.	Central and Northern Benin/ (Adifon et al., 2020)

In 2019, the World Bank Group conducted a study on "*CLIMATE-SMART AGRICULTURE INVESTMENT PLAN*" with the contribution of the Coat of Arms of Ivory Coast, Initiative for Adaptation of African Agriculture (Initiative AAA), International Center for Tropical Agriculture (CIAT), Climate Change, Agriculture and Food Security (CCAFS) which is provided an investment plan for climate-smart agriculture (CSA) in Côte d'Ivoire. Situation analysis indicates that climate change will impact the production of key agricultural products in the country, which will, in turn, impact each economic activity. Climate change will drastically alter what crops are suitable for a given place, reducing suitability across large areas but also creating pockets of increased suitability. Modeling using the International Model for Agricultural Commodity and Trade Policy Analysis (IMPACT) suggests that the landscape of economic incentives will change, offsetting the loss of ability for some crops while exacerbating it for others (World Bank Group, 2019). Concerning the yam cropping, their study shows that the percentage point difference in yield and area of production with different levels of climate change for yams will be reduced negatively in yield under Regional Climate Projection (RCP) respectively in 2030 and in 2050 (RCP4.5: -0.9%; -2.3% and RCP8.0: -1.0%; -2.4%) and increased in production in the same RCP for respectively 2030 and 2050 (RCP4.5: 0.2%; 0.5% and RCP8.0: 0.1%; 0.4%) (Table 10).

Table 10. Percentage point difference in yield and area of yam production with different levels of climate change in Côte d'Ivoire. **Source:** (World Bank Group, 2019)

	Difference in yield (SSP3)				**Difference in area of production (SSP3)**			
	RCP 4.5		**RCP 8.0**		**RCP 4.5**		**RCP 8.0**	
	2030	2050	2030	2050	2030	2050	2030	2050
Yams	-0.9	-2.3	-1.0	-2.4	0.2	0.5	0.1	0.4

Note. SSP = Shared Socioeconomic Pathways; RCP = Representative Concentration Pathway.

5. Conclusion and Outlooks

Documentary research is a task to be carried out before embarking on a practical study. It enables gathering information from original papers about the work to be carried out. The objective of this study was, therefore, to review the state of the art on the topic entitled: «Yam production-related agro-climatological risks and yam yield modeling in Côte d'Ivoire». Four official national platforms (Ministry of Agriculture and Rural Development (MINADER), National Center for Agricultural Research (CNRA), National Agency for Rural Development Support (ANADER), Airport, Aeronautical and Meteorological Exploitation and Development Company (SODEXAM)) and six scientific search engines were investigated in this study including Theses.fr, African Journal Online, Science Direct, Google Scholar, WorldCat and Semantic Scholar. None of the results from these ten (10) search platforms found a study on Côte d'Ivoire according to the search terms. On the other hand, eight (8) related works in this field were retained and investigated. These documents deal with the climatic impact on yam and yam yield modeling in West Africa and the French Antilles (Guadeloupe). Regarding climate impact on yam cropping, the authors note the low annual yam yield rate caused by rainfall uncertainties, heat waves and soil infertility. As far as modeling, is concerned, three (3) models are the most widely used. These are Approach for Land Use Sustainability (SALUS) model, the Environmental Policy Integrated Climate (EPIC) model and the Cropping Systems Simulation (CROPSYST) model. In addition to these models, artificial intelligence through machine learning models had been used by some authors for yield prediction for several crops including yams. These models, as good as they are, present uncertainties and limitations in modeling studies and climate change on yam production. Concerning the yield modeling-based machine learning tools, the proposed prediction models are generalizable to the West African region and support large-scale data sets which increase uncertainties and large estimates in the outputs. On the other side, the variability of crop yields and season length simulated by SALUS, EPIC and CROPSYST models are highly dependent on the uncertainty of crop parameters and model calibration. These models, therefore, use simple relationships to represent yam growth and production. The pattern and magnitude of relationships between crop parameters and model output in these studies were consistent with typical responses of crop physiological processes and to the environment. However, few modeling studies have taken into account the dynamic simulation of disease effects and the simulation of crop phenology at the same time. This could be an advantage and improve the accuracy of the model. By doing so, the calibrated model could be used to improve fertilizer management in yam production and will solve a major problem in this sector for the greater happiness of yam farmers. Finally, it should be noted that all the models and tools used in these studies have been developed for several crops, so using them need to be accurately calibrated. In the case of yam, a specific model must be set up to fight against all kinds of environmental impact, as it is the main food crop in Côte d'Ivoire, with a production of 7853083.92 tonnes in 2021, the second most important in West Africa, and one of the most widely grown crops in Africa with 73493225.79 tonnes in 2021 according to Food and Agriculture Organization of the United Nations statistics.

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Authors Contributions

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