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# Ex ante mapping of favorable zones for uptake of climate-smart agricultural practices: a case study in West Africa

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## Abstract

Developing relevant decision-support tools for policymakers to support large-scale implementation of climate-smart agriculture in the Global South is challenging given the great diversity in biophysical, socio-technical, and organizational conditions. This article describes a pilot exercise inspired bythe recommendation domain literature that aimed at mapping, beyond “classical” biophysical and socio-technical variables, the institutional variables (i.e., the existence of policy incentives in national policy documents) that could influence the large-scale implementation of climate-smart agricultural practices. Four practices were considered: cereal-legume intercropping, fodder legume cultivation, farmer managed natural regeneration (FMNR) of *Parkia biglobosa*, and crop residue mulching. The biophysical and socio-technical variables were classified based on thresholds identified in the literature and mapped with a geographic information system. The policy documents considered were investment plans, adaptation plans for climate change, nationally determined contributions, and Technology Needs Assessments project reports. Sixteen policy documents for four countries were thoroughly reviewed and classified as unfavorable, intermediate, and favorable for the four selected practices, based on a decision tree built for that purpose. Our analysis shows that areas where biophysical, socio-technical, and institutional variables are aligned for the four practices considered are small, particularly for fodder legume cultivation and crop residue mulching. For cereal-legume intercropping, incentives from national policies strongly differ from one country to another while for FMNR of *Parkia biglobosa* policies are more homogeneously conducive across countries. Nonetheless, it was possible to identify areas where biophysical, socio-technical, and institutional dimensions of the transition toward climate-smart agriculture (CSA) were aligned, for example, cereal-legume intercropping in southern Mali. The delineating of favorable and unfavorable areas allows specific recommendations to be made for policymakers as levers for action differ in favorable, intermediate, and unfavorable zones. Based on the exploration made for the four practices, this study highlights the need for further articulations from local to national scale to implement CSA.

**Key words: climate change, recommendation domains, innovation**

## 1. Introduction

The climate-smart agriculture (CSA) concept emerged in 2010 in order to overcome the challenges presented by climate change to agricultural systems and to better incorporate agriculture in international climate negotiations. CSA identifies synergies and trade-offs among food security, adaptation and mitigation as a basis for informing and reorienting policy in response to climate change (Lipper et al., 2015). This is increasingly controversial because of a lack of clarity and a tendency to overlook mitigation issues (Saj et al., 2017; Fallot, 2016). Concerns also exist that CSA could be co-opted by some of the world's biggest industrial contributors to climate change (Pimbert, 2015). For some authors, the concept does not focus enough on the agroecological practices and socio-technical networks used by farmers to adapt to climate change (Altieri et al., 2015). Despite these controversies, the concept offers an operational analytic framework to articulate the challenges posed by climate change (in terms of adaptation and mitigation) and sustainable development (Lipper et al., 2015).

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Several countries of the Global South have adopted CSA as a strategy to achieve nationally determined contributions for climate action (unfccc.int/focus/ndc_registry/items/9433.php). Over the past few years, approaches have been proposed to prioritize climate-smart solutions in collaboration with agricultural development actors, and to develop mechanisms for wide-scale adoption (Campbell et al., 2016; Mwongera et al., 2017). However, when applied at a national scale, they do not fully succeed in considering the diversity of biophysical, socio-technical, and organizational conditions at sub-national levels. Thanks to the increased availability of high-resolution, publicly available geospatial biophysical and socioeconomic data, the recommendation (or development) domains approach has emerged (Pender et al., 2004). This approach aims at identifying locations where similar combinations of geospatial data exist in order to guide decision-making. Based on biophysical and socioeconomic variables, the approach enables defining regions where farmers' circumstances are homogeneous so that they could be potentially eligible for similar development interventions. There are two distinct types of approach: similarity analysis and threshold-based approaches. Similarity analysis relies on existing documented success stories to link them with available geospatial data. However, evidence of success stories for a given technology or a given practice is seldom available and threshold-based studies may prove more appropriate. The threshold-based approach defines categories for specific attributes in the available geospatial layers to define geographic boundaries where technology uptake is most likely (Notenbaert et al., 2017). Several studies have therefore been carried out to define recommendation domains for dual-purpose maize varieties (Notenbaert et al., 2013), conservation agriculture (Tesfaye et al., 2015), and CSA options for livestock feed and grassland management (Notenbaert et al., 2017). These studies account for a range of biophysical and socioeconomic variables, but tend to overlook current institutional arrangements in specific countries that play a role in technological transitions (Geels, 2011). Countries across the Global South exhibit contrasting and uneven policies and institutional arrangements. Adding an institutional dimension to the definition of recommendation domains is therefore crucial if relevant recommendations to policymakers are to be made.

In this article, we propose a generic approach that enables the identification for policymakers of favorable zones where biophysical characteristics, socio-technical variables**,** and institutional environment are aligned and could trigger the implementation of specific CSA practices. Our work seeks to map the zones considered less favorable by disentangling constraints related to biophysical and socio-technical obstacles with those related to the institutional environment. By doing so, we aim to develop a prototype decision-support tool that moves beyond technical mapping focused only on biophysical and socioeconomic variables. This pilot exercise was applied to West Africa, a region particularly vulnerable to climate change. In West Africa, annual rainfall cycles are strongly determined by the position of the intertropical convergence zone. The region's climate is therefore one of the most erratic in the world, and predictions of future changes in climate (especially rainfall) and impact on crop production are highly uncertain (Müller, 2013). Despite contrasting scenarios of climate change for this region, all models predict an increase in climate variability (Cooper et al., 2008; Jalloh et al., 2013). In some Sahelian areas, the production of nine of the major crops would become unviable by 2050, with the most affected crops being maize and bananas (Rippke et al., 2016). Climate change will consequently pose huge challenges to food security (Waongo et al., 2015) and particularly to child nutrition and health (Johnson and Brown, 2014). Additionnaly, West Africa is experiencing a significant growth in agriculture greenhouse gas emissions accounting for 20% of agriculture emissions in the continent (Tongwane and Moeletsi, 2018).

Our analysis considers four agricultural practices with a climate-smart potential, and relies on the spatialization of a set of biophysical, socio-technical, and institutional variables. These three variables considered differed across practices, but mainly revolved around soil and climate characteristics, population density, and policy incentives. The following sections present the steps of the approach, the variables selected, and the lessons drawn from the mapping intended for decision support.

## 2. Materials and methods

### *2.1. Choice of CSA practices*

Although FAO's CSA sourcebook (2013) provides many examples, CSA is usually described in terms of objectives to be reached and not in terms of the means to be employed to reach those objectives. This leaves it open to users to decide on the approach and type of interventions they consider ”climate smart” (Torquebiau et al., 2018)**.** We selected four agricultural practices contributing to food security, adaptation, and mitigation that were (i) indicated as very relevant for this area (Zougmore et al., 2018; Partey et al., 2018) and (ii) prioritized in a participatory exercise on CSA practices in West Africa (Andrieu et al., 2017). These practices were (i) cereal-legume intercropping, (ii) fodder legume cultivation, (iii) FMNR of *Parkia biglobosa*, and (iv) crop residue mulching. Selecting various practices that may present contrasted biophysical, socio-technical, and organizational conditions of implementation aimed at testing the difficulty of applying our methodological approach.

Cereal-legume intercropping consists of simultaneously growing cereal and pulse crops in the same field. This traditional practice has been neglected in recent decades in favor of pure stands of cereal crops, particularly in subhumid regions because of the increased use of draught animals (Vall et al., 2006). Intercropping can have a positive effect on the three pillars of CSA by (i) sustainably increasing productivity (e.g., Falconnier et al., 2016; Rusinamhodzi et al., 2012) and diversifying food sources, (ii) stabilizing yields (Raseduzzaman and Jensen, 2017), and (iii) potentially decreasing greenhouse gas (GHG) emissions (e.g., Shen et al., 2018). Sorghum-cowpea and maize-cowpea intercropping were considered.

Fodder legume cultivation has an impact on the three pillars of CSA by (i) enabling sustainable productivity growth in livestock farming systems (Amole and Ayantunde, 2014; Masikati et al., 2014),

(ii) reinforcing system resilience thanks to the provision of nutritious fodder for livestock (Pugalenthi et al., 2005), and (iii) mitigating GHG emissions. Mitigation takes place through the supply of a legume fodder that is (i) more digestible than cereal straw, thus less methanogenic for ruminants, and (ii) rich in protein, which lowers the need for imported concentrates (even if the existing rates of consumption are relatively low) to maintain a constant level of production (Doreau et al., 2016; Vayssières et al., 2016). The legume chosen for our study was mucuna (*Mucuna pruriens*).

*Parkia biglobosa* is an endemic tree species known as *néré* or the African locust bean. The protection of *Parkia biglobosa* integrates the three pillars of CSA. Its combination with crops can help to strengthen crop productivity due to its impact on soil organic matter (Partey et al., 2018). This tree can be used for food (fermented seed, flour), animal feed (flour), numerous medicinal purposes, and as fuel and construction material (Kater et al., 1992; Orwa et al., 2009). This wide range of uses can strengthen farming system resilience. Moreover, this tree offers potential for climate change mitigation through carbon sequestration (Corbeels et al., 2018).

Mulching with crop residues contributes to a sustainable increase in productivity thanks to soil organic matter enrichment and erosion reduction (Erenstein, 2002), provided that nitrogen is not limiting crop production (Rusinamhodzi et al., 2011). It can also stabilize yield and thus strengthen resilience by helping to prevent soil water evaporation (Bationo and Mokwunye, 1991). It can contribute to mitigation through soil organic carbon sequestration when other conservation agriculture requirements are met (Corbeels et al., 2018).

### *2.2. Methodological approach*

The approach starts by identifying the zones where the biophysical and socio-technical conditions are most favorable for the different CSA practices. Then, the broader backdrop of national policies (institutional conditions) that are favorable or unfavorable for these practices is identified.

This involves three steps: (i) the definition of the biophysical, socio-technical, and institutional variables to be considered; (ii) the map building; and (iii) the validation of the prototype.

### 2.2.1. Definition of variables

#### 2.2.1.1. Biophysical and socio-technical variables

We formulated hypotheses on possible levers and locks, that is, biophysical and socio-technical factors that could facilitate or limit the implementation of each practice. A variable was proposed to represent this lever or lock (Table 1). Numerical thresholds were defined so that each variable was divided into three categories: unfavorable, intermediate, or favorable. For a given variable, “unfavorable” does not mean that the practice is not feasible. It means instead that the value taken by the variable can limit its implementation (e.g., low yields below a given rainfall threshold). In what follows, we briefly describe biophysical and socio-technical variables for each of the four CSA practices. Table 2 gives an exhaustive list of the thresholds and categories for each variable as well as the source and description of the spatialized data used for the classification.

Four biophysical variables and two socio-technical variables were considered for the feasibility of cereal-legume intercropping (Table 1). The first biophysical variable was rainfall, with sorghum, maize, and cowpea having specific rainfall needs (Dugje et al., 2014; Assefa et al., 2010). The second biophysical variable was land cover; forested areas, urban areas, and flooded areas were considered unfavorable for the implementation of this practice. Soil drainage and soil depth were additionally factored in because sorghum, maize, and cowpea cannot tolerate waterlogging and need well-drained soil to thrive (Singh et al., 1985). The first socio-technical variable was rural population density, with land pressure modifying farmers' objectives and constraints. When rural population density is low, and land is not a constraint, farmers are likely to turn mainly to pure crops in rotation with fallows. However, as population densities increase and arable land becomes limited, farmers have more incentive to increase land productivity with intercropping (Falconnier et al., 2018). Livestock density was considered as the second socio-technical variable. Intermediary livestock density (Table 2) was considered favorable because then legume residues can be valorized (Ajeigbe et al., 2010). When livestock become too dense, free-grazing animals may damage the legume at harvest.

Six variables were identified as relevant for the feasibility of fodder legume cultivation (mucuna). Suitable rainfall, pH, temperature, soil drainage, and soil depth were taken into account (Table 1 and Table 2). Also considered was livestock density because mucuna is chiefly dedicated to animal feed. Intermediary livestock densities were deemed favorable for mucuna production for reasons similar to those for the cereal-legume intercropping practice.

Six variables were also considered for FMNR of *Parkia biglobosa*. *Parkia biglobosa* is native to West Africa and is mainly distributed on Guinean and Sudanese savannahs stretching up to the Sahel from West Africa to Uganda (Hopkins and White, 1984). Rainfall (Ecocrop, 2010), soil drainage, and soil depth were taken into account. This tree has a deeper soil preference than crops. Because of its multiple uses, livestock density and rural population density are crucial variables. For both livestock and rural population density, intermediate values allow the integration of tree products onto markets. Higher values (Table 2) threaten the survival, propagation, and regeneration of the trees because of land over-exploitation or excessive grazing by livestock (Gaisberger et al., 2017). Protected areas where harvesting trees is not authorized were also considered and excluded (Table 2).

Crop residue mulching does not involve the introduction of a particular plant species and the variables considered differed slightly from those used for the preceding practices (Table 1). Mulching requires a minimum amount of crop residues (Ranaivoson et al., 2017; Lahmar et al., 2012) and therefore biomass productivity thresholds (net primary productivity, expressed in carbon) allowing sufficient biomass production were determined (Table 2). We considered that 40% of the biomass produced in a field could be used for mulching, with the remaining 60% corresponding to other uses (Andrieu et al., 2015). The amounts of carbon were converted into kilograms of dry matter, considering 1 kg of dry biomass for 0.5 kg of carbon (Mathew et al., 2017). Crop residue mulching was deemed more interesting in Sahelian areas (rainfall 200–600 mm) with sandy soils of lower fertility where the addition of organic matter and improved soil moisture are crucial (Mando and Stroosnijder, 1999; Lahmar et al., 2012). Socio-technical limitations were related to competing uses of harvested residues. Human population density and livestock density were considered. With high livestock densities, crop residues for mulching compete with animal feed, whereas, in highly populated areas, they compete with their use as a source of energy and construction material (Bationo and Mokwunye, 1991; Andrieu et al., 2015; Mulumba and Lal, 2008).

*TABLE 1 and TABLE 2 here*

#### 2.2.1.2. Institutional variables

We considered the existence of policy incentives in national policy documents. We consulted national investment plans, that is, the implementation tools of the CAADP (Comprehensive Agriculture Development Program in Africa), aiming to make national agricultural policy interventions consistent with those of the common agricultural policies of the Economic Community of West African States (ECOWAS). We also considered national adaptation plans for climate change that were promoted after the 7th session of the Conference of the Parties (COP), and nationally determined contributions (NDC), presented in the 21st session of the COP in Paris. We also considered the reports (when available) produced under the Technology Needs Assessments (TNA) project, supported by the United Nations Framework Convention on Climate Change (UNFCCC). The TNA project aims at supporting countries in the identification of their technological needs in terms of adaptation and mitigation. We made this exploration for four countries where the information was easily accessible: Burkina Faso, Mali, Côte d'Ivoire, and Senegal. However, in some cases, the last version of some documents was not yet published; in this case, we used the latest available version. We first analyzed whether or not each document was favorable for the practice by thoroughly reading the documents to understand the context and the consistency of discourses and to avoid misinterpretation. We used a decision tree (Figure 1). We started by searching whether the document was mentioning the practice in generic terms (e.g., promotion of soil and water management practices in the case of crop residue mulching). If there were no generic mention of the practice, the document was not considered (case 0 in Figure 1). If the practice itself was specifically mentioned, we considered the policy context to be favorable (case 3 in Figure 1). If the practice itself was not mentioned (e.g., soil and water management mentioned but crop residue mulching not mentioned), there were two possibilities. If a competing technology or practice was highlighted (e.g., the document does not mention mulching and promotes building dams for water management, or promotes the use of residues not for mulching but for other uses), we considered that the situation was unfavorable (case 1 in Figure 1). When no competing practice was mentioned, the document was deemed intermediate (case 2 in Figure 1).

We then ranked the different documents to handle the issue of divergent recommendations: the national investment plans, initially designed as a means for African countries to affirm their agricultural policy, were considered the most important. This recommendation prevailed in the case of heterogeneity across documents. Development actors usually identify climate change adaptation as more relevant to West African countries than mitigation (emissions per inhabitant are low in the region) (Andrieu et al., 2017); therefore, we accorded more importance to the adaptation plans than to the NDCs (when the investment plan did not mention the practice). Within the same type of documents (for example, between the evaluation of technological needs action plans), the principle of a minimum rank between documents was applied, considering that full support is needed if a relatively unknown practice is to be truly promoted.

*Figure 1 here*

### 2.2.2. Map building

For each practice, we built two maps: one combining biophysical and socio-technical variables and the other including institutional variables. We decided to make two disctinct maps in order to highlight two processes occurring at different scales. We constituted a spatialized data system (GIS) to overlay the biophysical and socio-technical variables and their values based on their category (1 = unfavorable, 2 = intermediate, 3 = favorable): when a pixel took different values for different variables, the minimum prevailed, assuming that a single unfavorable condition could hinder the implementation of the practice. The overlay of the different GIS layers was used to highlight the areas where the potential for implementing a CSA practice was the highest. We developed policy maps by zooming in on four countries (Burkina Faso, Mali, Côté d'Ivoire, and Senegal).

### 2.2.3. Validation of the prototype by expert opinion

To validate the choice of variables and thresholds, the prototype developed was presented to five experts who were different from those who undertook the analysis (i.e., study co-authors) and who were chosen for their expertise in agronomy, livestock science, and West African political context. The experts did not invalidate the variables selected but rather made suggestions to interpret results and use the prototype. Their inputs are reflected in the subsequent sections.

## 3. Results

We first present the feasibility zones for the four CSA practices according to the biophysical and socio-technical conditions across West Africa. We then present the policy incentives for these practices in Burkina Faso, Mali, Côte d'Ivoire, and Senegal. Finally, we present what the recommendation domains are for these practices considering all biophysical socio-technical, and institutional variables in the four countries.

### 3.1. *Biophysical and socio-technical feasability of CSA practices*

According to the biophysical and socio-technical variables considered, cereal-legume interrcroping and fodder legume had the smallest areas of feasibility (colored areas in Figure 2a and 2b). FMNR of *Parkia biglobosa* and mulching of crop residues had the largest area of feasibility.

*Figure 2 here*

No "favorable" zone was identified for FMNR of *Parkia biglobosa* because deep soils could not be found in areas with favorable rainfall. For cereal-legume intercropping, fodder legume, and crop residue mulching, such favorable areas exist but were limited and corresponded to the green pockets in Figure 2a, b, and d. These green pockets correspond to 3.7% of the total area of feasibility for cereal-legume intercropping (3.4% for sorghum intercropped with cowpea, 4% for maize intercropped with cowpea), 3.1% for fodder legume, and 2.6% for mulching. With zooming at a national scale, it seems that the distribution of favorable areas (e.g., for maize-cowpea intercropping in Senegal, Figure 3) could also be explained by dense river and road networks. Roads and rivers did not appear in the literature analysis for the practices considered. But the locations of rivers and roads are likely correlated to variables such as population and livestock density, which were considered in our analysis.

*Figure 3 here*

### **3.2.** ***National policy incentives***

The countries expressed either homogeneous or constrasting support for the four indentified practices.

*TABLES 3, 4, 5, 6 here *

Cereal-legume intercropping was explicitly mentioned in only one of the 16 policy documents analyzed. Other soil and crop management practices such as composting, crop-livestock integration, and the use of mineral fertilizers were highlighted more frequently (Table 3). Fodder legume cultivation (mucuna) was explicitly mentioned in two of the 16 documents (Table 4). Five of the 16 policy documents were deemed to be unfavorable because they promoted other alternatives for improving animal feeding. The remaining documents (6 out of 16) were referring to animal feeding in generic terms without a clear specification on the practices to be promoted. FMNR of native trees such as *Parkia biglobosa* was mentioned extensively in all the documents analyzed and therefore the policy environment was always favorable regardless of the country (Table 5). The analyzed documents did not specifically mention mulching with crop residues, and prioritized other soil and water management practices (e.g., irrigation) or different uses of crop residues (e.g., for energy production) (Table 6).

Consequently, in the final ranking, the policy documents in the study countries were homogeneously favorable to FMNR of *Parkia biglobosa* (Figure 4c), homogeneously unfavorable to crop residue mulching (Figure 4d), and contrastingly supportive for cereal-legume intercropping and fodder legume cultivation (mucuna) (Figure 4a,b).

*Figure 4 here*

### 3.3. CSA recommendation domains

Areas where biophysical and socio-technical conditions are aligned exist, but were limited in their size in the four countries (inexistent for *Parkia biglobosa* and favorable area ranging from a minimum of 0.5% of the total area of feasibility in the case of mucuna in Côte d'Ivoire to a maximum of 9.3% of the feasibility area for cereal-legume intercropping in Burkina Faso). Institutional variables limited the feasibility of crop residue mulching in all four countries, fodder legume cultivation in Burkina Faso, and cereal-legume intercropping in Senegal and Burkina Faso because the associated policy documents were deemed to be unfavorable to their implementation. The only area where biophysical, socio-technical, and institutional dimensions were aligned was southern Mali for cereal-legume intercropping (i.e., biophysical, socio-technical, and institutional variables were all classified as "favorable") and corresponded to 3.2% of the feasibility area.

## 4. Discussion

### *4.1. Which lessons for decision-making?*

Our analysis showed that there is no "silver bullet" practice that could be disseminated large-scale across West Africa. This finding is in line with other studies on recommendation domains showing that only small areas match the favorable conditions for both biophysical and socio-technical criteria (e.g., Tesfaye et al., 2015). Other studies show that processes of technological transition are "situated" due to the complexity of the levers that need to be articulated (e.g., Duru et al., 2015; Hakmi and Zaoual, 2008). We also demonstrated the relevance to consider synergies between biophysical, socio-technical, and institutional factors: although some areas were favorable considering biophysical and socio-technical variables, the policy environment was not always conducive in its current framing. This was particularly the case for mulching that was not promoted in any of the the analyzed policy documents.

The practices selected in our analysis were not necessarily those promoted by development structures. Nonetheless, they are well-known practices endorsed by research for decades without having been widely adopted by farmers. This weak adoption of practices promoted by research in West Africa has often been mentioned in the literature (Cour, 2001; Herrero et al., 2010; Nziguheba et al., 2010; Van Rijn et al., 2012). The lack of organized value chains, the limited stakeholder involvement in the formulation of problems, and limited technology development are mentioned as possible explanations (Faure et al., 2010). Low adoption may also be due to a lack of linkages between local conditions favorable to the implementation of practices and the broader institutional arrangements at the national level. Our maps added institutional conditions, as these can restrict the uptake of innovations (Geels, 2011).

The approach tested in this method is intended to guide interventions of policymakers aiming at promoting CSA. It makes a complementary contribution to other initiatives permitting participatory prioritization of practices and interventions nationally (Campbell et al., 2016**;** World Bank Group. 2019). These methods are based on workshops with stakeholders that use the information produced by experts (on cost-benefit of practices, on risks, or on productivity under future climate scenarios) to define interventions. Our method particularly permits highlighting the diversity in biophysical, socio-technical, and organizational conditions that will affect the implementation of the practices. The process relies on publicly available geo-spatial data and can be easily and quickly implemented by regional research institutes with basic GIS skills and expertise on locally relevant CSA practices. For example, data analysis for this study took six months and could easily be integrated into a participatory process involving farmer representatives, extension workers, researchers, and policymakers.

Drawing from our analysis, there are two possible strategies for policymakers: (i) in favorable areas where biophysical, socio-technical, and institutional variables are aligned, a deeper exploration is needed to understand what is currently occurring on the ground and what the specific drivers and lock-ins are for the implementation of CSA practices; (ii) in moderately favorable (intermediate) areas, investments should focus on the limiting dimensions at stake (institutional, socio-technical, and/or biophysical when feasible). This can imply, for example, being more explicit on the nature of the practices that are promoted in the policy documents, exploring mechanisms to regulate livestock density through land charters (Dabire et al., 2017), or improving biophysical dimensions such as soil drainage through appropriate agricultural practices.

The proposed maps should not be considered as prescriptive tools for policymakers indicating technological packages to implement in a particular area. They are rather tools to guide discussions with other development stakeholders. A useful prospect could be their use with a range of stakeholders (e.g., NGOs, civil society, policymakers, scientists, actors of the private sector) to define the practices to be explored; the biophysical, socio-technical, and institutional variables to be considered; and to build consensus on the weighing of these different variables (see Brandt et al. (2017) for a useful example).

### *4.2. How can the decision support tool be improved?*

The limited spread of favorable areas for the four identified practices can be a matter of concern for adaptation potential of smallholder farmers across West Africa. However, exploring a wider range of CSA options, for example, supplemental irrigation and use of forecasts (Thornton et al., 2018), would potentially give a more optimistic picture. The biophysical and socio-technical variables used in this study are those classically considered in other recommendation domain studies (i.e., human and livestock density, see, e.g., Notenbaert et al., 2013; Tesfaye et al., 2015). Including other variables, such as distance to market would help to refine the areas identified depending on the practice considered. Such variable play a key role in access to institutional assets (Bansha Dulal and Shah, 2014).

The areas identified depend on the thresholds chosen for the variables considered. These thresholds are based on a literature review, but contrasting values for the same thresholds were found. Furthermore, some thresholds deemed unfavorable could locally prove to be favorable. For example, livestock densities deemed unfavorable for cereal-legume intercropping do not necessarily lead to crop damage:

beyond a certain stocking rate, the livestock system shifts to a stall-based system with crop residue harvesting to avoid crop-livestock interactions (Audouin et al., 2015).

The method proposed makes targeting possible, but it cannot ensure that an area identified as favorable is effectively so. It allows a preliminary sorting to determine whether to pursue further investigations. Adding to the expert validation, a field evaluation that identifies the development programs involving similar practices could inform gaps between potential and actual feasibility and help to identify key variables in play. Studies on recommendation domains indeed tend to overlook the importance of the local context: even within a favorable zone, significant variation exists between different types of farmers based on production objectives and resource endowment (Giller et al., 2011) and a finer targeting of best-fit options corresponding to farm characteristics and expectations is still necessary (Descheemaeker et al., 2016). Although the need to couple the two approaches (recommendation domains and farm typologies) is acknowledged (e.g., Thornton et al., 2018), there are to our knowledge no studies doing so. Widely accessible cross-sectional household data (e.g., Frelat et al., 2016) would offer a good avenue to bridge that gap.

In this study, we considered only national policy texts without looking at the critical institutions in charge of policy implementation, that is, effective translation of policy into action. By comparing national investment plans to actual investments in Senegal, Gabas et al. (2015) found important discrepancies in the funding allocated per sector, even if the actions undertaken were more or less consistent. The authors also demonstrated that policy priorities can change rapidly, for example, following elections. Differences between policy documents and their effective implementation also lie in the fact that these documents reflect more the country's position in relation to international donors than some nationaly identified priorities. Our maps could play a role in guiding the implementation of policy documents and actual investments when integrated into a participatory exercise with development actors.

## Conclusions

In order to identify areas in West Africa where biophysical, socio-technical, and institutional favorable conditions are aligned and trigger the implementation of CSA practices, we (i) collected and analyzed biophysical and socio-technical variables and (ii) reviewed 16 policy documents. The information was summarized and mapped into a geographic information system. We showed that areas where biophysical and socio-technical variables are favorable are limited. Non-supportive policy documents, particularly for fodder legume (mucuna) cultivation and crop residue mulching in some countries, further constrain the feasibility of these practices in the four countries studied. This work highlights the challenge of aligning biophysical, socio-technical, and institutional dimensions. It also calls for specific thinking about interventions based on the areas identified. Indeed, the identification of the dimensions that constrain practice feasibility helps to orient interventions. A limitation of this sudy is the lack of consideration of the great diversity of smallholder farm resource endowments. We suggest that recommendation domain and farm typology approaches be coupled. For testing out the combination of both approaches a perspective for this work is to better describe the diversity of farming systems in southern Mali for cereal-legume intercropping, the only area where biophysical, socio-technical, and institutional dimensions were aligned.

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**Figure 1: Decision tree for classifying national policy documents as unfavorable, intermediate, or favorable to a given CSA practice in West Africa.**

**Figure 2: Mapping of the feasibility of cereal-legume intercropping (maize or sorghum with cowpea) (A), fodder legume (mucuna) cultivation (B), FMNR of *Parkia biglobosa* (C), and crop residue mulching (D) according to biophysical and socio-technical variables. Variables and their threshold values for classification are detailed in Table 2.**

**Figure 3: Mapping of feasibility of intercropping maize with cowpea in Senegal according to biophysical and socio-technical variables. Variables and their threshold for classification are detailed in Table 2.**

**Figure 4: Mapping of the feasibility of cereal-legume intercropping (A), fodder legume cultivation (mucuna) (B), FMNR of *Parkia biglobosa* (C), and crop residue mulching (D) according to institutional variables derived from the analysis of national investment plans, adaptation plans to climate change, nationally determined contributions, and Technology Needs Assessments project reports (see Tables 2, 3, 4, and 5 and Figure 1 for a description of the method).**

**Table 1: Variables considered for the biophysical and socio-technical mapping of zones favorable for four CSA practices in West Africa.**

| | **Cereal-legume intercropping (maize or sorghum with cowpea)** | **Fodder legume (mucuna) cultivation** | **FMNR of *Parkia biglobosa*** | **Crop residues mulching** | **Data sources** |
|---|---|---|---|---|---|
| *Biophysical variables* | | | | | |
| Rainfall | x | x | x | x | https://crudata.uea.ac.uk/cru/data/hrg/<br>CRU TS v 4.01 Gridded dataset; Harris et al. (2014); Date: 1990-2016; Resolution: 0.5° |
| Temperature | | x | | | http://worldclim.org/version2<br>WorldClim V2 Minimum Temperature; Fick and Hijmans (2017); Date: 1970-2000; Resolution: 5 minutes |
| pH | | x | | | https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1247<br>Regridded Harmonized World Soil Database v 1.2; Wieder et al. (2014); Resolution: 5 km |
| Soil depth | x | x | x | | http://ref.data.fao.org/map?entryId=c3bfc940-bdc3-11db-a0f6-000d939bc5d8&tab=metadata__Effective Soil Depth; FAO-UNESCO Soil Map of the World (2007); Resolution: 5*5 arc minutes |
| Soil drainage | x | x | x | | http://www.fao.org/geonetwork/srv/en/metadata.show?id=30558<br>Soil Drainage Classes; FAO-UNESCO Soil Map of the World (2007); Resolution: 5*5 arc minutes |
| Land cover | x | x | | | http://glcf.umd.edu/data/lc/<br>MODIS Land Cover; Channan et al. (2014); Date: 2001-2012; Resolution: 5'x5' |
| Biomass productivity | | | | x | http://sedac.ciesin.columbia.edu/data/set/hanpp-net-primary-productivity/data-download<br>Global Patterns in Net Primary Productivity, v1; Imhoff et al. (2004); Date: 1995; Resolution: 0.25° |
| *Socio-technical variables* | | | | | |
| Protected area | | | x | | http://gaez.fao.org/Main.html?ticket=ST-961368-3w99FHqLbEd5dBbNdVcj-cas#<br>Protected Area Types; FAO and IIASA (2012); Resolution: 0.083333° |
| Population density | x | | x | x | http://www.fao.org/geonetwork/srv/en/main.home#population<br>Rural Population Density 2000; Salvatore et al. (2005); Date: 2000; Resolution: 5*5 arc minutes |
| Livestock density | x | x | x | x | http://www.fao.org/geonetwork/srv/en/metadata.show?id=47949&currTab=simple<br>Cattle Distribution – Gridded Livestock of the World v 2.01; Robinson et al. (2014); Date: 2014; Resolution: 0.008333° |

**Table 2: List of variables and their levers and locks with associated thresholds for the definition of favorable zones for four CSA practices in West Africa. Category thresholds: 1 = unfavorable[1], 2 = intermediate, and 3 = favorable.**

| | **Cereal-legume intercropping** | | **Fodder legume (mucuna) cultivation** | | **FMNR of *Parkia biglobosa*** | | **Crop residue mulching** | |
|---|---|---|---|---|---|---|---|---|
| Variable | **Levers/locks** | **Category thresholds** | **Levers/locks** | **Category thresholds** | **Levers/locks** | **Category thresholds** | **Levers/locks** | **Category thresholds** |
| Rainfall | Maize requires a minimum of 700 mm/year to be productive without irrigation | 1: 1200-1500<br>2: 700-800<br>3: 800-1200 mm/year | Mucuna tolerates rainfall between 650 and 2500 mm but optimal growth is obtained between 1000 and 2000 mm.<br>Heuzé et al. (2015) | 1: 650-1000<br>2: 2000-2500<br>3: 1000-2000 mm/year | The tree is distributed over a wide range of rainfall zones but thrives between 400 and 800 mm/year.<br>Orwa et al. (2009), Ecocrop (2010),<br>Heuzé et al. (2019)<br>Booth and Wickens (1988) | 1:<300 mm/year<br>2: 300-400 and >800<br>3: 400-800 mm/year | In the Sahel (low rainfall area), the rate of soil degradation is very high. Mulching is thus to be favored in those areas where the soil is very degraded.<br>Mando andt Stroosnijder (1999) | 1: >1500<br>2: 600-1500<br>3: Sahelian zones (200-600 mm/year) |
| | Sorghum requires rainfall between 400 and 800 mm/year, and sorghum is mainly planted when rainfall does not permit a maize crop<br>Assefa et al. (2010).<br>Du Plessis (1998). Department of Agriculture, Forestry and Fisheries (2010). | 1: 400-450<br>2: 700-800<br>3: 450-700 mm/year | | | | | | |
| | Cowpea tolerates rainfall between 300 and 1500 mm/year and performs best between 500 and 1200 mm/year. Dugje et al. (2014) | See maize and sorghum (thresholds for maize and sorghum take into account cowpea suitability limits) | | | | | | |
| Temperature | | | Minimum temperature should not fall below 10 °C.<br>Ecocrop (2010) | 2: tmin 10-15 °C<br>3: >15 °C | | | | |
| Land cover | Agricultural land, grasslands, shrublands, and areas with mixed cover are favored. | 3: Agricultural land, grasslands, shrublands, and areas with mixed cover.<br>Excluded: flooded areas, built-up/urban areas, and forests. | | | | | | |
| pH | | | Optimal soil pH for mucuna is between 5 and 7.<br>Ministère de L'Agriculture, des Ressources Hydrauliques, de l'Assainissement et de la Sécurité Alimentaire (2018). | 2: 4-5 and 7-8<br>3: 5-7 | | | | |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| Soil drainage | Cowpea does not tolerate waterlogging FAO (2006), Gomez (2004), Singh et al. (1985) | 1: excessively and imperfectly drained<br>2: extremely and moderately well drained<br>3: well drained | Mucuna thrives best in well-drained soils. Aklamavo and Mensah (1997). |  | *Parkia biglobosa* prefers to grow in well-drained soils. Ecocrop (2010) | 1. excessively and imperfectly drained<br>2. C extremely and moderately well drained<br>3. well drained |  |  |
| Soil depth | Cereal and legume cultivation is less susceptible to drought stress in deep soils. Ecocrop (2010. | 1: 10-50<br>2: 50-100<br>3: above 100 cm | Mucuna prefers soil with a depth of more than 50 cm | 1: 10-50<br>2: 50-100<br>3: 100-150 cm | This tree prefers deep soils (more than 150 cm deep) but is sometimes found on shallow soils. Orwa et al. (2009), Ecocrop (2010) | 1: 0-50<br>2: 50-150<br>3: >150 cm |  |  |
| Biomass productivity |  |  |  |  |  |  | Mulching requires a minimum amount of crop residues (Ranaivoson et al., 2017; Lahmar et al., 2012) and therefore biomass productivity thresholds (net primary productivity, expressed in carbon) allowing sufficient biomass production were determined. | 1: 0.25-0.5<br>2: 0.5–1<br>3: >1 t/ha of residues |
| Rural population density | High rural population density spurs intensification and thus encourages intercropping. Intermediate population densities tend to favor sole cropping. Falconnier et al. (2018) | 2: 15-80<br>3: More than 80 and less than 15 people/km$^2$ |  |  | Human over-exploitation of land endangers existing trees and does not allow the planting of new trees. Gaisberger et al. (2017) | 1: 0-10<br>2: 30-100<br>3: 10-30 people/km$^2$ | Crop residues are also used as fuel, for construction, for medicinal purposes, etc. It therefore will be difficult to keep enough residues for mulch in areas where the population density is very high. Mulumba and Lal (2008) | 1: >80<br>2: 15-80<br>3: More than 80 and less than 15 people/km$^2$ |
| Livestock density | Livestock allow the valorization of crop residues, but an overly high density of animals would also endanger the crops. Onyibe et al. (2006), Ajeigbe et al. (2010). | 2: less than 15 or more than 40<br>3: 15-40 animals/km$^2$ | Livestock facilitate valorization and integration into the fodder market. Above a certain threshold, it is difficult to maintain livestock in the territory without endangering crop production. Dumas (personal communication) | 2: <15 and >40<br>3: 15-40 animals/km$^2$ | High livestock density allows market integration of *Parkia biglobosa* feed products (leaves, pods, branches, etc.). Overly intense grazing hinders the natural regeneration of the trees. Hopkins and White, (1984), Orwa et al. (2009), Gaisberger et al. (2017) | 1. 0-10<br>3. 10-50<br>2. >50 animals/km$^2$ | As crop residues are also used to feed livestock, mulching will be easier to implement in areas where the livestock density is not too high. Moreover, crop residues are threatened by rights of commonage in areas where livestock are numerous. Rodriguez et al. (2017), Bationo and Mokwunye (1991), Lahmar et al. (2012) | 1: >40<br>2: 15-40<br>3: <15 animals/km$^2$ |
| Protected areas |  |  |  |  | In protected areas, agricultural activities are not allowed and *Parkia biglobosa* cannot be exploited. |  |  |  |

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[1] Thresholds for 1 (unfavorable) does not apply when the conditions are not found across West Africa

**Table 3: Classification of five policy documents as favorable (3), intermediate (2), or unfavorable (1) for the support of cereal-legume intercropping in Mali, Côte d'Ivoire, Burkina Faso, and Senegal (see Figure 1 for a detailed description of the decision tree for the choice of the category).**

| Policy document | | Mali | Côte d'Ivoire | Burkina Faso | Senegal |
|---|---|---|---|---|---|
| National investment plan in the agricultural sector[1] | Information | Crop and soil management mentioned but no specific information | Promotion of organic amendment, legume cover-crop techniques, production and free distribution of legume seeds mentioned. No conflicting practice mentioned but cereal-legume intercropping not specifically mentioned. | Large-scale use of manure combined with mineral fertilizers highlighted. Intercropping not specifically mentioned. | Sustainable soil management techniques (soil restoration, compost production) mentioned. Increased capacity of chemical industries of Senegal (ICS) and Matam plant to improve fertilizer availability for farmers mentioned. |
| | Category | *Document not considered* | *Intermediate* | *Unfavorable* | *Unfavorable* |
| National Action Programme for Climate Change Adaptation (2007) | Information | No specific information on crop and soil management, manure mentioned | * | Intercropping presented as an “endogenous” practice that should be substituted by new technologies. | * |
| | Category | *Unfavorable* | * | *Unfavorable* | * |
| Nationally determined contribution (2015) | Information | Manure production, micro-fertilizer, and system of rice intensification (SRI) mentioned – no mention of intercropping | Organic fertilizers, household waste composting, and crop-livestock integration mentioned. Cereal-legume intercropping not explicitly mentioned. | Use of biodigesters for soil fertility management and creation of forests for soil conservation mentioned. Intercropping not specifically mentioned. | Manure management, rice cultivation, organic fertilizers, forest lands, and plantations mentioned. Intercropping not specifically mentioned. |
| | Category | *Unfavorable* | *Unfavorable* | *Unfavorable* | *Unfavorable* |
| Technology Needs Assessments and implement Technology Action Plans- Adaptation (2012) | Information | Intercropping highlighted for maintenance of land cover and soil water conservation. Cowpea-maize intercropping specifically mentioned. | Maximizing soil nitrogen enrichment with legumes (inoculation of soybean, groundnut, and cowpea seeds, burying postharvest biomass) mentioned. Intercropping not specifically mentioned. | * | Conservation agriculture (direct planting through mulch or legume cover crops) and other soil restoration options (Zaï, assisted natural regeneration, biochar, deep placement of urea in rice systems) mentioned. Cereal-legume intercropping not specifically mentioned. |
| | Category | *Favorable* | *Intermediate* | * | *Unfavorable* |
| Technology Needs Assessments and implement Technology Action Plans- Mitigation[2] | Information | Competing techniques mentioned: management of crop residues, use of compost and micro-dose fertilizers, fallow land, and system of rice intensification (SRI). | Sludge use and compost for soil fertilization mentioned. Intercropping not specifically mentioned. | * | Diffusion of reasoned fertilization techniques, crop diversification, short-cycle and salt-tolerant varieties mentioned. Millet and short-cycle cowpea varieties mentioned as examples. Intercropping not specifically mentioned, but no competing practice mentioned. |
| | Category | *Unfavorable* | *Unfavorable* | * | *Intermediate* |

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[1] 2014 for Mali and Burkina Faso, 2015-2017 for Côte d'Ivoire, 2011-2015 for Senegal

[2] 2006 for Senegal

* document not accessible/not analyzed

**Table 4: Classification of four policy documents as favorable (3), intermediate (2), or unfavorable (1) for the support of fodder legume (mucuna) cultivation in Mali, Côte d'Ivoire, Burkina Faso, and Senegal (see Figure 1 for a detailed description of the decision tree for the choice of the final category).**

| **Policy document** | | **Mali** | **Côte d'Ivoire** | **Burkina Faso** | **Senegal** |
|---|---|---|---|---|---|
| National investment plan in the agricultural sector[1] | Information | Favorable to fodder production without explicit mention of the type of fodder. Construction and support of livestock feed production unit, support for fodder seed producers. | Support for the production of fodder and fodder seeds mentioned. Fodder legumes not specifically mentioned; legumes mentioned in other parts of the document. | Transhumant pastoral systems highlighted. Livestock feed not mentioned. | Support for livestock feeding mentioned without specific mention of fodder legumes. |
| | Category | *Intermediate* | *Intermediate* | *Unfavorable* | *Intermediate* |
| National Action Programme for Climate Change Adaptation (2007) | Information | Forage crop (cowpea, pigeon pea) development project in the Niger Inner Delta: collection and production of seeds, dissemination of cultivation techniques and conservation methods. | * | Use of crop residues and fodder crops for animal feeding mentioned. Fodder legumes not explicitly mentioned. Dual-purpose crops and fallows as fodder mentioned. | * |
| | Category | *Favorable* | * | *Intermediate* | * |
| Nationally determined contribution (2015) | Information | Livestock not mentioned. | Support for production of fodder and fodder seeds mentioned. Fodder legumes not specifically mentioned; legumes mentioned in other parts of the document. | Conservation of coarse fodder, hay, and crop residues. Fodder legumes not specifically mentioned. | Development of pastoral units and pastoral insurance, improvement of livestock genetics, production, and health mentioned. Fodder legumes not specifically mentioned. |
| | Category | *Document not considered* | *Intermediate* | *Unfavorable* | *Unfavorable* |
| Technology Needs Assessments and implement Technology Action Plans- Adaptation (2012) | Information | Livestock associated with the improvement of fodder crops. A specific project targets leguminous fodder plants (bourgou, cowpea, and stylosanthes). Mucuna not explicitly mentioned in the project document – no competing practice mentionned. | Livestock not mentioned. | * | Constitution and conservation of fodder stocks mentioned. Fodder legumes not specifically mentioned. |
| | Category | *Favorable* | *Document not considered* | * | *Intermediate* |
| Technology Needs Assessments and implement Technology Action Plans- Mitigation[2] | Information | Livestock mitigation management for livestock identified: animal waste management and improved parks. No specific mention of fodder cultivation. | Livestock not mentioned. | * | Extensive livestock and scarcity of fodder and water resources mentioned. Cattle feeding strategy not mentioned. |
| | Category | *Unfavorable* | *Document not considered* | * | *Unfavorable* |

[1] 2014 for Mali and Burkina Faso, 2015-2017 for Côte d'Ivoire, 2011-2015 for Senegal

[2] 2006 for Senegal

* document not accessible/not analyzed

**Table 5: Classification of three policy documents as favorable (3), intermediate (2), or unfavorable (1) for the support of FMNR of *Parkia biglobosa* in Mali, Côte d'Ivoire, Burkina Faso, and Senegal (see Figure 1 for a detailed description of the decision tree for the choice of the final category).**

| **Policy document** | | **Mali** | **Côte d'Ivoire** | **BurkinaFaso** | **Senegal** |
|---|---|---|---|---|---|
| National investment plan in the agricultural sector[1] | Information | Explicit mention of agroforestry in general. Additional focus on trees with greater added value such as shea. | General promotion of reforestation and raising awareness among communities about agroforestry mentioned. | Improved coordination of official support to the agro-silvo-pastoral sector mentioned. Non-woody forest products mentioned. Agroforestry practice and diverse tree products highlighted. *Parkia biglobosa* not specifically mentioned. | Dissemination of agroforestry techniques, extension of community woods, and prevention of bush fires and valuation of non-timber forest products mentioned. |
| | Category | Intermediate | Favorable | Favorable | Favorable |
| National Action Programme for Climate Change Adaptation (2007) | Information | Agroforestry mentioned in a project to raise awareness and organize populations for the preservation of local natural resources. ***Parkia biglobosa*** **n**ot specifically mentioned. | * | Fighting against bushfire and anarchical forest clearing mentioned as a national forest policy. Growing of medicinal species, orchards installation, and agroforestry to produce fodder mentioned. *Parkia biglobosa* not specifically mentioned. | * |
| | Category | Favorable | * | Favorable | * |
| Nationally determined contribution (2015) | Information | Forestry and agroforestry with reforestation and energy uses (Jatropha and other trees) mentioned. | Improvement of silvicultural species, agroforestry promotion, and degraded lands restoration mentioned. | Implementation of good forestry and agroforestry techniques (selective cutting of firewood, assisted natural regeneration, controlled clearing) explicitly mentioned. | Forest lands and plantations, reforestation, and forest management mentioned. *Parkia biglobosa* not specifically mentioned. |
| | Category | Favorable | Favorable | Favorable | Intermediate |
| Technology Needs Assessments and implement Technology Action Plans- Adaptation (2012) | Information | Agroforestry and plantation techniques highlighted. Importance of forests mentioned and list of products similar to those of *Parkia biglobosa*. *Parkia biglobosa* not explicitly mentioned. | Reforestation of 500-ha teak plantation intercropped with legume and subsistence crops mentionned (i.e., a technique similar to FMNR of *Parkia biglobosa* **).** | * | Assisted natural regeneration, agroforestry, and provision of multiple products (fodder, fruits, lumber, firewood, medicinal products, and by-products such as gum) mentioned. Conservation techniques of endemic trees by local populations also mentioned (not specifically *Parkia biglobosa*). |
| | Category | Favorable | Intermediate | * | Favorable |
| Technology Needs Assessments and implement Technology Action Plans- Mitigation [2] | Information | Reforestation and agroforestry activities, sale of carbon credit, and sustainable management for energy use highlighted. *Parkia biglobosa* not specifically mentioned. | Reduction of deforestation with production of briquettes from agricultural and forestry waste mentioned. Reforestation or promotion of agroforestry not specifically mentioned. | * | Enclosure of community forest, forage enrichment tests, and reforestation with adapted species mentioned. |
| | Category | Favorable | Unfavorable | * | Favorable |

[1] 2014 for Mali and Burkina Faso, 2015-2017 for Côte d'Ivoire, 2011-2015 for Senegal

[2] 2006 for Senegal

* document not accessible/not analyzed

**Table 6: Classification of five policy documents as favorable (3), intermediate (2), or unfavorable (1) for the support of crop residue mulching (see Figure 1 for a detailed description of the decision tree for the choice of the final category).**

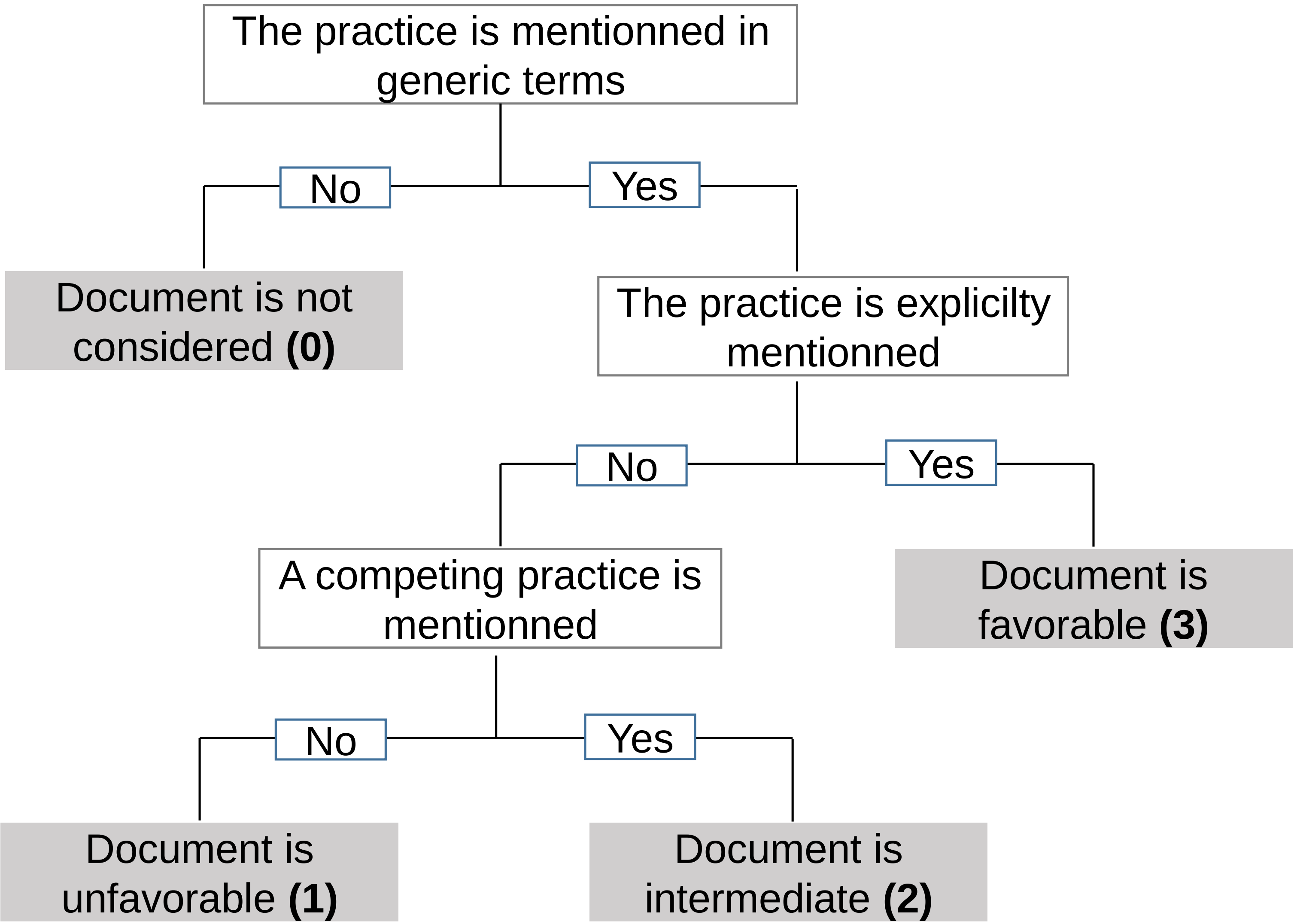
| **Policy document** | | **Mali** | **Côte d'Ivoire** | **Burkina Faso** | **Crop residue mulching** |
|---|---|---|---|---|---|
| National investment plan in the agricultural sector[1] | Information | Water management mentioned, with local irrigation schemes (lowlands, small dams, and market gardening schemes), development of pastoral hydraulics, water reservoirs with boreholes creation. | General objectives mentioned for water and soil management. Crop residue mulching not specifically mentioned. | Water management through management of banks, irrigation, drinking water, and lowlands mentioned. Crop residue mulching not specifically mentioned. | "Water Control" program including interventions around hydraulics (transfers, retention ponds, drip irrigation, boreholes) mentioned. Crop residue mulching not specifically mentioned. |
| | Category | *Unfavorable* | *Document not considered* | *Unfavorable* | *Unfavorable* |
| National Action Programme for Climate Change Adaptation (2007) | Information | Water management mentioned, with small irrigation, dams, ponds, and forage creation. Energy potential of straw highlighted. | * | Crop residue mulching presented as an “endogenous” practice (such as anti-erosive bunds, improved Zaï, half-moon, grass strips, assisted natural regeneration, hedgerows ) that should be substituted by new technologies. | * |
| | Category | *Unfavorable* | * | *Unfavorable* | * |
| Nationally determined contribution (2015) | Information | Rainwater harvesting and storing and use of energy biomass mentioned. | Water management with strengthened watershed planning and coordination, development of agro-pastoral dams, development of new hydro-agricultural sites and water reservoirs, improvement of irrigation efficiency, valorization of rainwater and floodwater mentionned. Use of agricultural residues for energy. | Soil and water conservation techniques (stone barriers, dikes, semi-circular bunds, terraces, half-moons with manure, agroforestry, dune fixation, construction of water reservoirs and modern wells, high-volume drilling, dams, ponds, diversion of watercourses) mentioned. Crop residue mulching not specifically mentioned. | Agricultural biomass for energy production mentioned. Crop residue mulching not specifically mentioned. |
| | Category | *Unfavorable* | *Unfavorable* | *Unfavorable* | *Unfavorable* |
| Technology Needs Assessments and implement Technology Action Plans-Adaptation (2012) | Information | Water management highlighted, with small irrigation, dams, and cisterns. Soil management mentioned, zero-tillage with retention of residues on the soil highlighted. | Water management with watershed planning and coordination for joint management of groundwater and surface water and improved irrigation efficiency mentioned. Burying of postharvest biomass mentioned. | * | Biochar, wastewater reuse, tanks, drip irrigation, desalination (but not for agriculture) mentioned. Crop residue mulching not specifically mentioned. |
| | Category | *Favorable* | *Unfavorable* | * | *Unfavoable* |
| Technology Needs Assessments and implement Technology Action Plans-Mitigation (2012)[2] | Information | Straw for energy production proposed. | Use of agricultural residues for energy production mentioned. | * | Small-scale hydraulics (hillside reservoirs, retention ponds, anti-salt dikes, and groundwater recharge areas) mentioned. Mulching mentioned for the south of the country to fight against salinity. |
| | Category | *Unfavorable* | *Unfavorable* | * | *Unfavorable* |

[1] 2014 for Mali and Burkina Faso, 2015-2017 for Côte d'Ivoire, 2011-2015 for Senegal

[2] 2006 for Senegal

* document not accessible/not analyzed

Figure 1


The practice is mentionned in generic terms

No

Yes

Document is not considered **(0)**

The practice is explicilty mentionned

No

Yes

A competing practice is mentionned

Document is favorable **(3)**

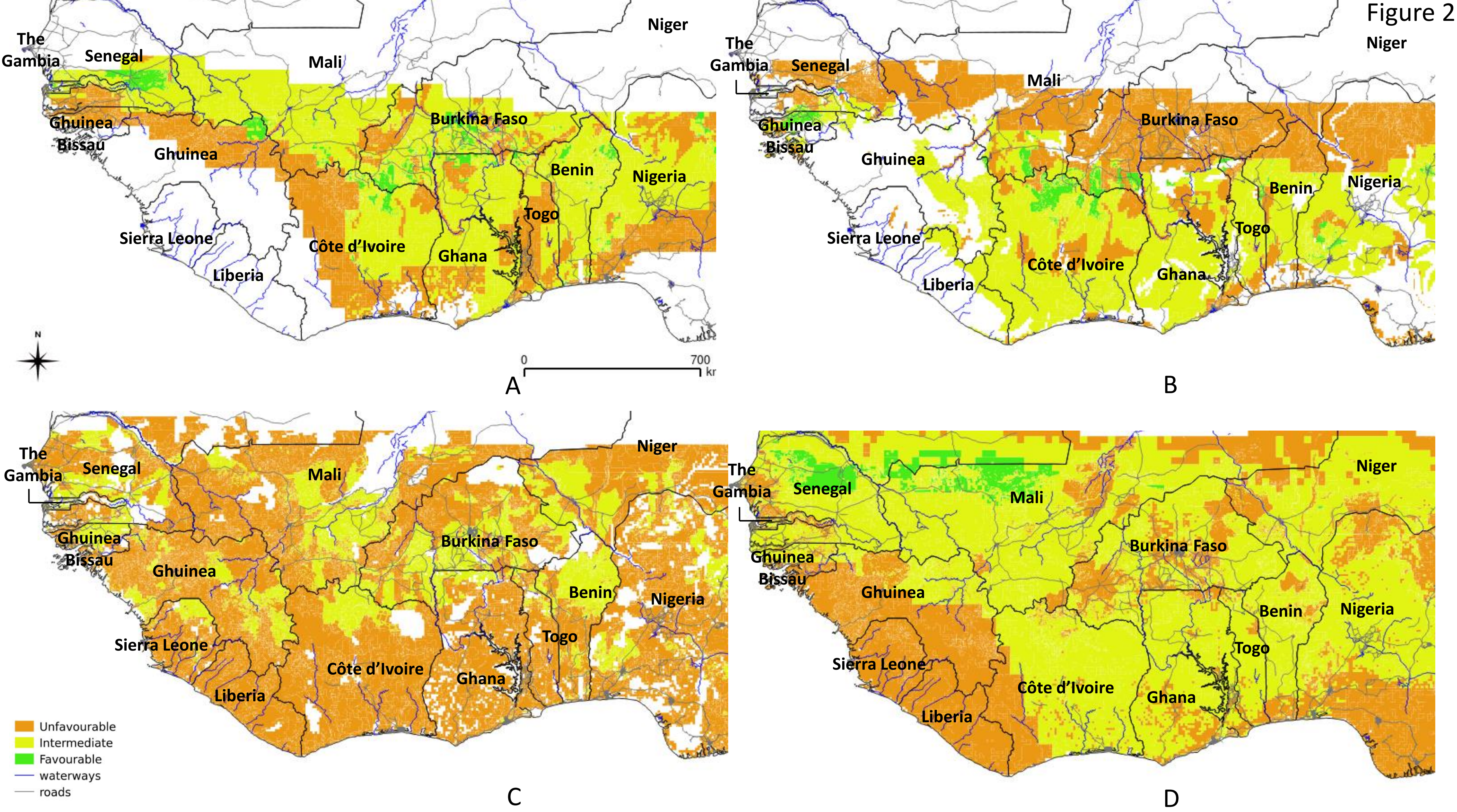
No

Yes

Document is unfavorable **(1)**

Document is intermediate **(2)**

Figure 2



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Niger
Ghuinea Bissau
Ghuinea
Burkina Faso
Benin
Nigeria
Togo
Sierra Leone
Liberia
Côte d'Ivoire
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700
km
Unfavourable
Intermediate
Favourable
waterways
roads

Figure 3

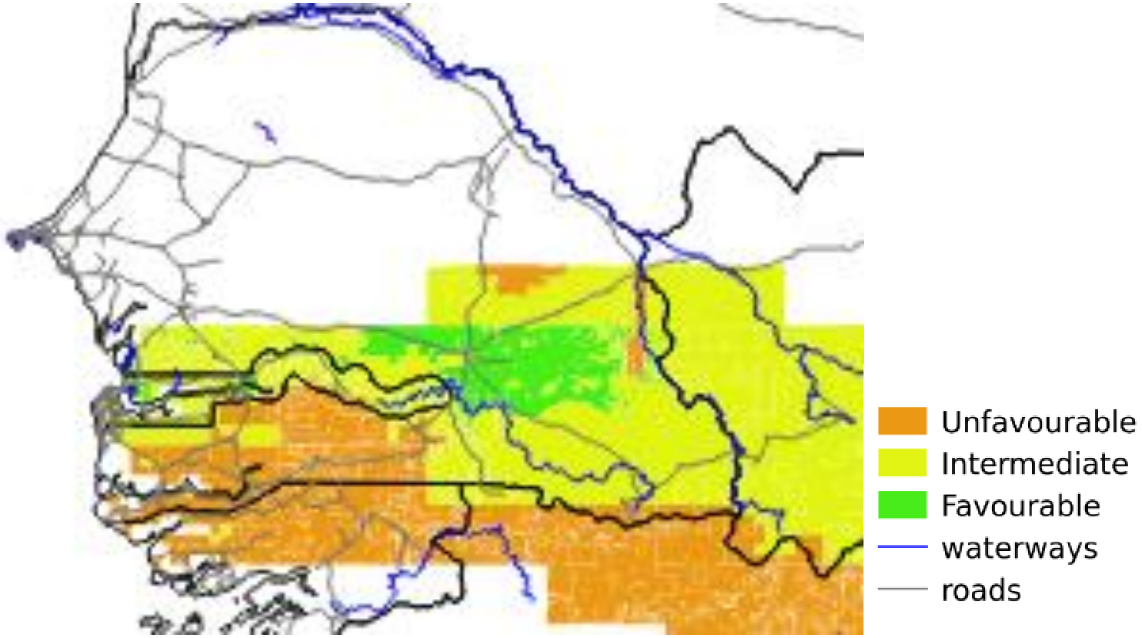
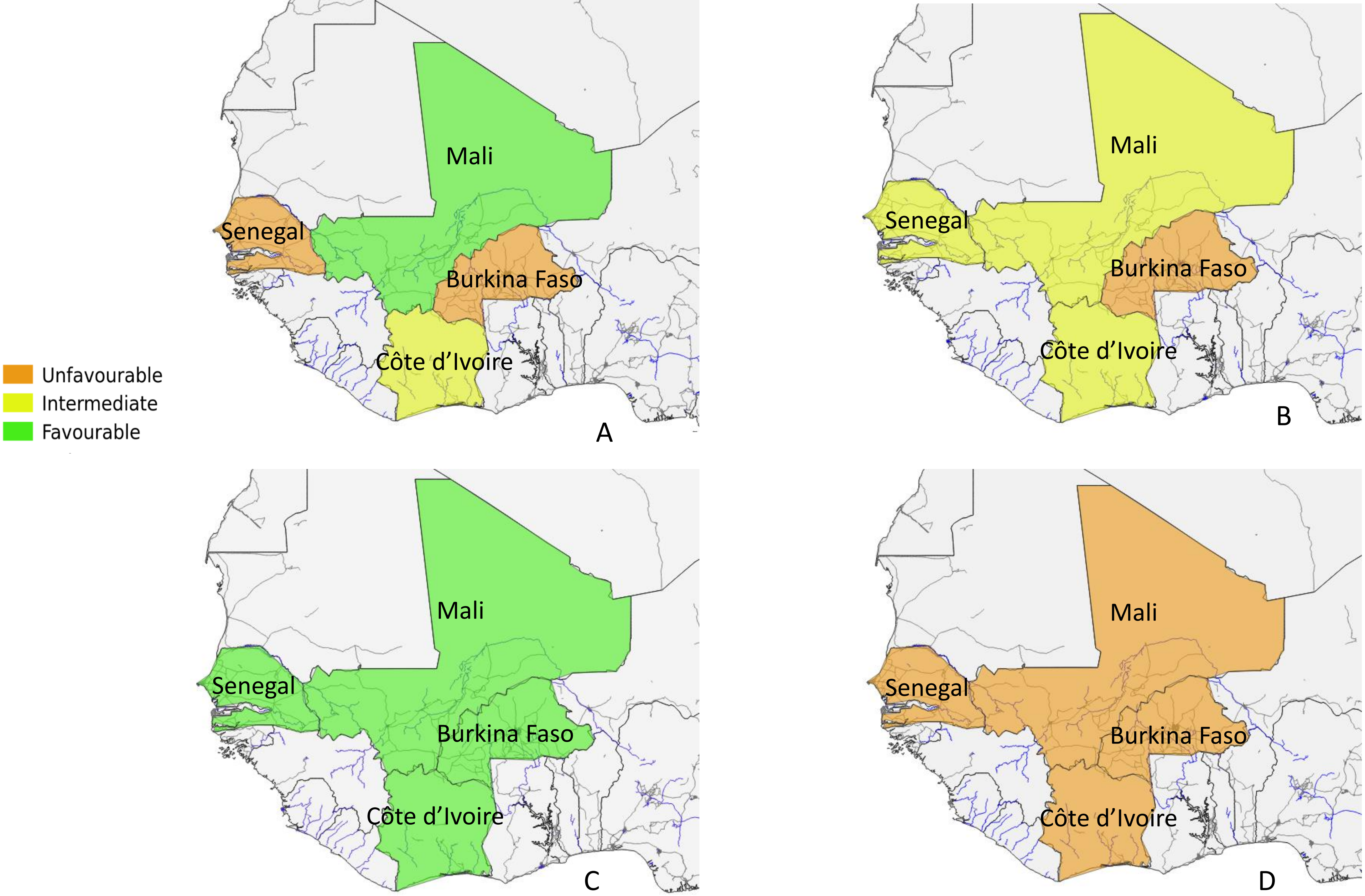


Figure 4



🟧 Unfavourable
🟨 Intermediate
🟩 Favourable
Mali
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Côte d'Ivoire
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