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Determinants for Deployment of Climate-Smart Integrated Pest Management Practices: A Meta-Analysis Approach

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Abstract: Following the development and dissemination of new climate-smart agricultural technologies to farmers globally, there has been an increase in the number of socio-economic studies on the adoption of climate-smart integrated pests' management (CS-IPM) technologies over the years. In this study, we review empirical evidence on adoption determinants of CS-IPM technologies and identify possible science-policy interfaces. Generally, our review shows that socioeconomic and institutional factors are influential in shaping CS-IPM adoption decisions of farmers. More specifically, income was found to positively influence the adoption of CS-IPM technologies while land size owned influences CS-IPM adoption negatively. Registered land tenure (registered secure rights) positively influences CS-IPM technologies' adoption, implying that efficient land markets that enable competitive and fair distribution and access to land, more so by the vulnerable but efficient smallholder producers do indeed increase the adoption of CS-IPMs technologies. Social capital, achieved via farmers' organizations is also central in fostering CS-IPM technologies' adoption, just as markets reforms that minimize market failures regarding access to credit, labor, and agricultural information, which could indirectly hinder farmers' use of CS-IPM practices. Functional extension systems that improve farmers' awareness of CS-IPM do also improve CS-IPM technologies' adoption. However, the adoption of CS-IPM technologies in Ghana and Benin is slow-paced because of factors like lack of access to farm inputs that facilitate uptake of these technologies, lack of credit facilities, and limited extension services among others. Interestingly, our review confirms that CS-IPM technologies do indeed reduce and minimize the intensity of pesticide usage and foster ecosystem (environmental and human) health. Therefore, this review unearths strategic determinants of CS-IPM adoption and makes fundamental guidance around climate-smart innovations transfer and environmental policies that should be prioritized to curb environmental pollution and ensure agricultural ecosystems' sustainability.

Keywords: socio-economic determinants; agricultural technologies; climate-Smart; integrated pest management technologies (CS-IPM)

1. Introduction

Because agriculture is the principal means of survival for many vulnerable populations globally [1], recent improvements in agricultural productivity have enabled considerable reductions in global hunger in recent decades [2]. However, the agricultural sector

faces many challenges including trade barriers, scarcity of resources, breakdown of market systems, unstable and ineffective socio-economic policies, insecurity, increasing population pressure, unsustainable and soil degrading agronomic practices, and dilapidation of the environment [3]. However, the sector is aggressively threatened by the negative impacts of weather unpredictability and climate change [3]. Moreover, the severely affected are the resource-poor smallholder farmers particularly those challenged with food security and safety [4]. There are already efforts being made at various levels to address this threat via the adoption of various climate-smart practices [3, 5]. Climate-smart practices are also integrated with pest management practices that often allow the use of 'nature-based solutions' to enable effective pest control, thus leading to lesser usage of chemical pesticides [4]. To address these challenges and adapt the agricultural sector to the imminent climate change, and as well reduce the sector's emissions, Climate Smart Agriculture (CSA) is progressively gaining in importance with a wider global endorsement more so in strategic farming systems for instance the cocoa production system in Ghana [1, 3, 6]. CSA aims to optimize social, environmental, and economic benefits while sustainably bringing about development by anchoring on three key strategic pillars that include: (1) sustainable improvements in agricultural productivity and household income; (2) adjusting to and building formidable household resilience to climate change, and (3) minimizing and/or eliminating greenhouse gases emissions if compared to conventional agricultural practices. Moreover, relying only on agrochemical crop protection to guarantee improvements in agriculture leads to pesticide overuse, leading to both direct and indirect antagonistic effects, from grave to chronic poisoning of the environment, thus leading to severe and chronic environmental deterioration [7]. Hence, to achieve effective climate-smart agriculture, improved agricultural technologies need to be integrated with pest management, thus must be climate-smart integrated pest management (CS-IPM) compliant. CS-IPM has been defined and elaborated in various ways. However, the key aspect that has been pointed out severally as the most important for any CS-IPM approach is that the CS-IPM practice must integrate the context of the affected ecosystem into the pest control strategy. Moreover, the goal must not be to control the pests in the short-term more so in a restricted area but should be to use naturally available resources and factors sustainably, so to avoid further outbreaks of pest populations [8]. Therefore, the preferred and effective CS-IPM practice or approach must integrate spatial and temporal dimensions as well as a multi-dimensional environment. Therefore, CS-IPM practices are explicit concerning the target crop, the region where the crop is grown, and the time during the crop's growth when the practices must be applied. Hence based on such a ground, understandably, crop rotation is one of the centrally noble CS-IPM practices. As regards the comparison between CS-IPM and other pest control measures like Chemical Crop Protection that can be classified under the regular IPM, it's evident that CS-IPM hinges on natural controls and more effectively work with these natural forces to achieve more effective pest control, rather than working against the natural controls which yields lesser pest control [8]. Therefore, CS-IPM technologies and practices allow the attainment of longstanding steadiness between the environment and agricultural production systems thus fostering sustainable food systems. Henceforth, implementation of CSA technologies and practices as regards integrated pest management (IPM) is majorly an aspect of varying determinants depending on a range of factors like location, cultures of people, accessibility to information, and socio-economic set-ups in different areas [9]. On the other hand, regular IPM generally focuses on the use of multiple integrated tactics simultaneously to suppress pests while maximizing economic gains [4, 8, 9]. However, since most of the vulnerable populations especially in the global south are dependent on agriculture, which is heavily dependent on the natural environment, it is prudent that innovations must be in place to maximize the well-being of the environment equally as economic gains [4]. Therefore, CS-IPM knowledge must be developed, and appropriately packaged for adoption by farming communities and policy. Sadly, much of the developing world has been slow at adopting CS-IPM innovations and practices due to the huge knowledge gaps that exist [1,3,4,9]. Therefore, in this meta-analysis review we contribute to closing this knowledge gap by

understanding the key socio-economic factors that influence the deployment of CS-IPM practices use the internet as the primary source of articles reviewed for this meta-analysis study to profile determinants (socio-economic) for the implementation of climate-smart integrated pest management. However, this being a recent innovation in agriculture, articles on CS-IPM were very limitedly available, especially on Africa, and limited our review to only a few numbers of articles. Although our focus was global, we had a keen consideration for Ghana and Benin, because these are action countries selected for the implementation of the “Accelerating the Impact of CGIAR Climate Research for Africa” (AICCRA) project which is a new CGIAR (Consultative Group on International Agricultural Research) initiative whose goal is to increase access to climate information services and authenticated climate-smart agriculture practices and technologies in Africa. This study is therefore central in advising priorities and investment decisions of AICCRA and similar projects, as well as strategic policies intended to preserve the environment and sustainable food systems through CS-IPM practices.

1.1. Brief Elaborations on CS-IPM and IPM

Broadly, CS-IPM can be described as a process that is realizable through the synchronization of knowledge about the biology of the targeted pests, the technology available to curb these pests’ proliferation, and the pests’ environment, while observing the minimum possible economic thresholds and damage to humans and the environment [4, 5, 10, 11, 12, 13, 14, 15, 16, 17]. However, Egan et al. [4] more particularly defined CS-IPM as an integrated approach that uses conservative and naturally eco-system compatible practices to minimize or stop pest insects, pathogens, and weeds to subsequently minimize farmers’ dependence on chemical pesticides and thus damage to human and environmental health. Therefore, CS-IPM practices comprise bio-pesticides, biologically based pest control methods, the use of crop varieties, and other related practices [4, 10, 13, 17, 18, 19]. Thus, CS-IPM programs embody a practical alternative that can sustainably optimally minimize the continuous use of chemical pesticides and their related toxicity to the environment resulting from pesticide overuse, [4, 10, 20, 21, 22, 23]. Probable paybacks of the CS-IPM approach are therefore multiple and may include savings on farm production costs, limited human and animal exposure to pesticides thus fostering a wider availability of organic foods, and eventually improved human health and environmental value [4, 10, 15, 17, 18, 19, 21, 22, 23]. Therefore, embracing climate-smart agricultural practices, innovations, and technologies has the desired potential to upsurge the needed agricultural productivity and eventually enhance farm households’ livelihoods sustainably while cementing their resilience to several climate-based shocks [4, 22, 23]. Moreover, Climate Smart Agricultural Technologies (CATs) are also viewed as an up-to-date approach to upwardly transform and reinvent agricultural production towards sustainable and significant reductions in global food insecurity and malnutrition [6, 5, 11, 19, 22, 23]. Precisely though, a desired CS-IPM approach predicts changes in multiple pest pressures because of climate change and in reaction undertakes to deploy effective monitoring, forecasting, and management actions to ensure effective farm output and One Health benefits for people and the environment at large [3, 4, 10, 19, 23]. However, CS-IPM adoption and implementation have been low globally leading to adverse climate change effects in certain regions for instance northern Ghana [9, 11, 12]. Moreover, different factors including the role of institutions, farm households’ socio-economic context, the location’s biophysical, and characteristics of the new technology among others are vital determinants in the implementation and adoption of CSATs, including CS-IPM [4, 5, 11, 18, 17, 19, 20, 21, 23]. Next, we elaborate on these various factors that centrally determine the deployment of CS-IPM in their exactness as unearthed by this meta-analysis in the results and discussions section. On the other hand, IPM in general focuses on a synchronized usage of various strategies to achieve optimal control of any pests (vertebrates, pathogens, or insects) while maximizing economic benefits and the wellness of the respective ecosystem [9, 14, 16, 21, 23]. Therefore, under IPM various pests must be targeted simultaneously and monitored consistently [4,

14, 16, 21, 23]. Furthermore, under IPM one must ensure that pesticides are used viably economically, and that the strategies used to combat pests are well integrated either vertically (within certain pest types) or horizontally (across various pests) [4, 9, 14, 16, 21, 23]. Hence, in a nutshell, IPM practices adopted must generate economic benefits, minimize the usage of chemical pesticides, and preserve good human and environmental health. But because such desired integration has been generally difficult to achieve across several farming systems, thus failing to maximize desired and sustainable environmental and human health benefits, and the economic benefits, this has led to more targeted and efficient methods of pest management that maximize targeted environmental and economic benefits, for instance, CS-IPM [4, 14, 21, 23].

The rest of the paper is organized as follows: next, we present the methods used to conduct this meta-analysis review, after which we present our results and discuss them. Finally, we conclude with guidance on feasible investment and policy alternatives.

2. Materials and Methods

2.1. Review Methodology

In selecting the papers to consider for this review, we executed a rigorous, robust, and comprehensive literature review methodology for conducting a meta-analysis review, as has been recently applied by Gwara et al. [16]. This methodology is preferred because it allows transparency and reproductivity. Specifically, the chosen approach did not limit our search criteria but granted us the opportunity to stretch this search criterion enabling us to a diverse and comprehensive review process. Moreover, a scoping review methodology allows the smooth synthesizing of research evidence in a reproductive manner [17].

Our focus in this review was on the studied population being of farmers, interactions of the population and CSATs, comparisons of CSATs and other conventional farming technologies, outcomes of adopted and implemented CSATs including CS-IPM ones, and the study design employed in analyzing research objectives being at least quantitative or qualitative or both. Our bias was more towards a population of farmers who use CSATs mainly in Ghana and Benin. The intervention of focus was the “the determinants of implementation of CS-IPM in Ghana and Benin in comparison with other African countries and other cases in other parts of the world especially Asia”. The outcome was the implementation of CSATs based on varied determinants with a bias in Ghana and Benin. Again, the designs of these studies were generally categorized as either qualitative or quantitative, while others employed a mixed set of methods. This design was also recently used by Gwara et al. [16], and Gwara et al. [17]. We show our simplified identification and selection criteria of considered studies in Figure 1, as was elaborated by Moher et al. [18] and Page et al. [19] with the objective of thoroughly reviewing all possible original studies that empirically and soundly analyzed CS-IPM socio-economic aspects globally but with a keen focus on developing countries especially Ghana and Benin

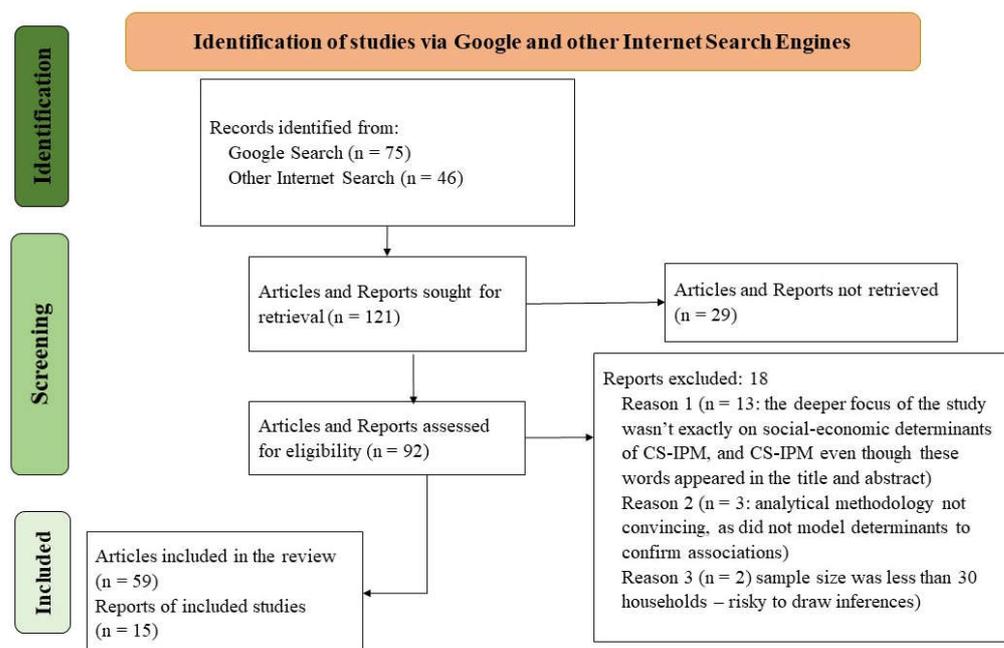


Figure 1. Identification and selection methodology of considered studies.

2.2. Identification of relevant studies and search strategies

As a strategy, the study involved performing the primary search in the database of Google and other internet search engines using keywords such as “determinants of the implementation of CSATs specific to Ghana and Benin and then to the rest of Africa and Asia, climate-smart technologies, Integrated Pest Management technologies, and One health Innovations Ghana and Benin.” This review was restricted to covering only peer-reviewed journal articles that were available and published in English but specifically addressed CSATs more so in the regions mentioned above. We also used the aspect of searching CSATs respective to integrated pest management (IPM) like “drought-resistant seeds” to access more articles on respective practices. We more dominantly used a method of handpicking articles included in the electronic database of Google scholar about Climate Smart Agriculture to get more information on CSATs and related practices. Articles in Google Scholar are more complete empirically with proper abstracting, indexing, depth, and breadth of information [16, 17]. We finally identified through our Google and other internet search efforts, 121 studies but 29 were dropped, and considered 92 studies for this review (see Figure 1).

2.3. Screening Strategy and Employed Eligibility Criteria

The study sourced and screened 121 journal articles from the internet for their relevance to the objectives of this study, first based on the title. Those studies which satisfied the primary inclusion criteria were further finely vetted based on their abstracts. Subsequently, complete-text screening was only done for those studies that were relevant for the needed data. After this complete-text screening process, a total of 92 articles were identified as potential sources of information on CSATs as was needed by the review process, and finally, 74 were considered for this study (see Figure 1). More specifically, our review executed an approach that was typically descriptive analytically to source data from the selected articles that satisfied the inclusion conditions and standards. This was made more possible by following the framework elaborated and used by Gwara et al. [16, 17]. Data extracted included names of the authors, year, location, the determinant of CSATs implementation studied, the study design used, study location, and the considered sample size. This study, therefore, gathered variables that give a quality assessment of the socio-eco-

conomic determinants of CS-IPM technologies and practices, from the studies that were considered. Moreover, variables such as determinants of climate-smart agricultural technologies, CS-IPM, and Climate Smart Agriculture in general, were also considered.

3. Results and Discussions

Key Identified Socio-economic Determinants for the Deployment of CS-IPM Practices

3.1. Poor access to suitable farming apparatus

The poor access to CS-IPM suitable farm tools and apparatus is a substantial blockade to deploying CS-IPM innovations in Africa [20, 21]. CS-IPM innovations may not inevitably necessitate that farmers acquire more farming equipment or apparatus than that used in conventional agriculture, however, some needed apparatus and equipment for CS-IPM may be particular but not readily available. For example, with respect to CSA where CS-IPM is a subdivision, certain conventional agriculture tools and apparatuses can be used while others would need adjustment for instance hand hoes may need reductions in size to ably dig CSA compatible planting formations. On the other hand, insufficient inputs and farming materials, restricted access, and incapacity to afford better-quality seeds for crops and cover crops, inorganic fertilizers, and suitable pest management tools and products, do also hamper the deployment of CS-IPM innovations, and CSA in general to optimal levels [20]. Moreover, proper CS-IPM improves yields by enabling biological procedures and farming practices that upsurge soil fertility, pests, and weed control [14, 22].

3.2. Access to credit and finance

Smallholder farmers targeting to adopt CS-IPM innovations and CSA practices, in general, are usually restricted by insufficient financial power that is needed to invest in needed capital for instance land, farming tools, improved seeds or breeds, labor, and other farm inputs. As noted by Milder, et al. [20], CSA is, therefore, generally more gainful in the long-term in comparison to conventional farming. However, realizing these longstanding gains necessitates heavy preliminary investments that are usually risky, hugely expensive, and unaffordable to smallholder farmers. These smallholder farmers do particularly fear to take-on such risks because such threatens their household food security. During the times when their food security is threatened, farmers usually give up on CS-IPM practices. Thus, long-lasting adoption of CS-IPM practices is more probable when CS-IPM delivers substantial paybacks in the initial one or two years of adoption [4, 14, 23]. However, these immediate gains are more probable when CS-IPM practices are employed alongside good and appropriate agronomic practices and good-quality seeds. Most often, technology choices are restricted by lack of financial resources and or awareness about how these resources could be accessed, if were available. CS-IPM practices are therefore costly, and farmers must have seed money to use these practices or get subsidies to facilitate CS-IPM adopt [23]. The lack of sufficient financial muscle to obtain needed farm materials and inputs is therefore a significant impediment to SC-IPM adoption by smallholder farmers. For instance, usually more labor would be needed than what is possibly available, and the situation has been worsened by rural-urban migration of youths, the prevalence of HIV, other diseases, and malnutrition [24]. Therefore, regional financing for CS-IPM research, capacity building, and economic incentives that stimulate CS-IPM development and acceptance should be considered for the successful deployment of CSA in general [23].

3.3. Physical and social infrastructures

An enabling physical infrastructure that includes water supply and management facilities that can enable irrigation, transport and markets facilities, communication, processing, and storage infrastructure are essential for smallholder farmers to be able to implement CS-IPM, and CSA in general. Social infrastructure is also essential for instance farmers' organizations. Poor and insufficient infrastructure limits the adoption of CS-IPM

innovations, particularly for subsistence farmers, whose investment decisions rely on revenues generated from sales of their produce [25, 26]. Moreover, the ecosystem of area certain location which comprises the location's people and the various activities they engage in; the location's topography, weather conditions, and general climate; and the location's political, economic, social, and cultural structure can effectively encourage or discourage adoption of given CS-IPM practices [27]. In addition, strategic discrepancies in market alignments (i.e., the blend of subsistence and commercial farming practices versus virtuously subsistence farming practices), and probable mitigation alternatives, for instance, crop intensification versus livestock farming, do all influence one's decision to apply CS-IPM practices [25].

On the other hand, non-physical barriers comprise those factors that affect the environment desirable to practice CS-IPM. These are usually institutional elements that comprise a steady macroeconomic environment, functional institutions and policies, provision of incentives through markets, and leadership structures that facilitate the generation, dissemination, and usage of CS-IPM relevant technologies, practices, innovations, approaches, information, knowledge and skills, and public and private investments in human, social, natural, and capital [28]. In a community where institutions, policies, and markets are not effective, the generation and dissemination of information, technologies, and innovations become crippled, hence leading to farmers' deficient necessary awareness, knowledge, and skills to adopt pro-CS-IPM practices [25]. Moreover, obstructive land tenure systems, a lack of lucrative markets and safe post-harvest storage, meager financial services, frail farmer organizations, and minimal household incomes render it risky and unbearable for farmers to change from any of the conventional practices to CS-IPM ones [29].

3.4. Access to appropriate technologies and technological diffusion

Several of the adaptive approaches and strategies that are essential in managing climate change effectively, require appropriate practices, technologies, and innovations. For instance, the IPCC [30], denotes that the absence of suitable technologies can seriously limit a community's capability to implement CS-IPM innovations by reducing alternative choices of probable interventions. Adaptive strategies and capacities are likely to differ, based on access to a given technology at different levels of the target sectors. Therefore, the different levels and stages of the technology's adoption in communities and the communities' ability to adapt this technology to the local context are key determining factors of the community's capacity to change and accept this technology. Hence, community awareness to the new technologies and the utilization of these technologies continuously are central in cementing the adaptive capacity of these communities to CS-IPM innovations. Therefore, the technology's expansion and diffusion in communities are key worries associated with low CS-IPM adoption. Moreover, the sluggish distribution rate and adaptation of CS-IPM in Africa are partly attributable to low technology adoption [31]. In fact, the role played by extension services in diffusing technologies to farmers is hindered by farmers' poor financial capabilities, low technical skills, and threats of the technology that are interruptive to the prevailing household livelihood systems [32]. For example, to avert disease transmission, farmers put tree-crop defense barricades around cocoa farms. These disease barricades effectively minimize Cocoa swollen shoot virus disease infection rates [33]. Even though these barricade plantings take up land area, they are also a source of income working as an agroforestry extension where farmers grow crops like rubber, citrus, and palms etc. that all enhance effective CS-IPM practices. Therefore, monitoring tree health can effectively help farmers avoid major pest and disease occurrences [34]. Hence, appropriate capacity building of farmers through demonstration farms, appropriate extension services, and consideration of indigenous knowledge and feasible cultural practices are essential for meaningful technological transfer – which extends to CS-IPM innovations.

3.5. Benefits from the technology

The technology must be widely beneficial to households to foster its uptake. However, all components of benefits are hard to embody in each technology. For instance, appropriate technologies must be catering for ecological, economic, and social benefits to be widely adopted and accepted [7, 35, 36, 37]. For instance, farmers in SSA usually prefer technologies that fetch immediate and significant benefits especially economically than those whose benefits are achieved in the future, because subsistence farmers face immediate food security risks and high costs of production [38]. Yet, a lumpsum of the benefits of CSA, including CS-IPM practices, can mostly be attained in the longer term [11, 39]. Moreover, no analyses of costs and benefits for CS-IPM has been done yet but given that it is rated more complex than IPM in some instance, related CS-IPM cost especially in the starting phases may be high, hence threatening the immediate economic benefits targeted by most farmers [42, 43]. For instance, evidence shows that IPM practices improve crop yields to about 41%, and reduce pesticide use by about 31% which all increases net income received by farmers [40, 41]. Therefore, to enhance their uptake CS-IPM innovations must be beneficial to adopters especially regarding economic returns and food security sustainability. Nevertheless, the projected benefits of CS-IPM innovations would generally be high due to reductions in external negative [42, 43]. Negative external costs can arise from contamination of groundwater caused by heavy pesticide use [44], or severe pesticide poisoning that affects 1-3% of farmworkers globally, leading to numerous deaths. Moreover, even though farm households in low developed countries use about only 25% of global pesticides, these suffer about 99% of deaths from pesticide poisoning [45]. Other costly negative externalities include the unintentional killing of soil and water organisms that predate pests, soil and water pollution, and the death of several flora and fauna. Therefore, such external negative costs must be avoided for any CS-IPM innovation to be successful [11, 46].

3.6. Poor leadership, management, and governance structures

Leadership, governance, and management infrastructure reflects, influence, and guides the legal framework that shapes the socio-economic landscape of a society [32, 47]. Bad governance is a key inhibitor of the desired socio-economic developments that must foster the society's adaptation and adoption of CS-IPM and CSA in general. Incompetent societal management usually focuses on instant gains, thus those innovations needing heavy investments with later gains, for instance, CS innovations and practices like CS-IPM may not be prioritized [32]. Incompetent leadership may be characterized by corruption and failed systems and usually fails to guarantee institutional development and effectiveness which limits access to resources needed by communities to realize CS-IPM innovations [47, 48]. Therefore, poorly managed institutions fail to mitigate climate risks, and thus deployment of CS-IPM innovations, and institutional deficiencies lower communities' abilities to combat vulnerability to climate change [49]. Therefore, necessary improvements in policies and societal management are needed to make agricultural systems more compatible with CS-IPM innovations and thus resilient to changes in climate [50]. However, building suitable institutional adaptive capacity necessitates good coordination, empirical understanding of societal problems, candidness to addressing societal challenges, and candidness in exploiting opportunities, aggressive community participation, and solid political will [51, 52]. Therefore, for successful deployment of CS-IPM, critical elements like setting up a decent agenda for collaboration, capacity building, community involvement, raising awareness, rational investments, and suitable technological and governance structures must be available [32]. Unfortunately, Africa, where a large proportion of vulnerable smallholder farmers are, has generally inadequate supportive governance structures. Had they been adequate, they would have been appropriate pathways for providing suitable extension facilities, credit services, fairness in the allocation of resources, effective information diffusion, a decent policy environment, and functional social institutions that all foster deployment of CS-IPM innovations [53].

3.7. Policy Issues

In West Africa, there is yet to be a comprehensive policy, and a robust institutional framework on adaptation to climate change, and CS-IPM innovations especially by small-holder farmers. Improving policies and regulations as is projected for instance in Ghana, enables production and certification of biopesticides and other biologically based pest control products that are important nature-dependent solutions within the general CS-IPM innovations framework [47]. However, there are policies on various domains like land and water resources management, which could somehow enable the deployment of CS-IPM innovations [32]. Thus, unless the current gaps in concerned government policies are addressed, it will be tough to successfully deploy CS-IPM innovations, and CSA in general [32, 47]. Moreover, different sector-based policies must be coordinated and integrated to echo how the inter-linked sectors would address climate change, and thus deployment of CS-IPM innovations. Nevertheless, there has been some good steps to address these inconsistencies. For instance, many governments in Africa have agricultural plans that integrate and prioritize a climate change focus, for example the National Agriculture Investment Plans. Severally, however, these agricultural plans are hardly scientifically evaluated as business cases. Therefore, key doubts are inadequately measured before making decisions on the bio-physical, organizational, economical, and ecological barriers to the deployment of CS-IPM innovations, the success of the CS-IPM innovations at the farm level or the entire food system levels, comparative benefits, costs, risks, and the monitoring of the innovations' development and progress for appropriate learning [25]. Therefore, policies must be coordinated across sectors (within the private and public arenas) and cover a wide spectrum of key aspects surrounding the deployment of CS-IPM practices to achieve their adoption at scale. However, good funding and suitable expertise are essential to frame suitable CS-IPM plans and policies [45]. On the other hand, formidable community support, awareness-raising, and knowledge transfer would also be essential for the realization of appropriate up-to-date and harmonized policies that enable CS-IPM deployment [25, 45]. For example, communities of cotton farming households in northern parts of Benin, willingly pay annually a substantial amount per hectare for the diffusion of CSA extension services that include CS-IPM innovations [54]. Moreover, most cotton farming households in Benin, even though are largely illiterate and vastly poor, were willing to pay for training and regular advisory extension services on CS-IPM innovations due to these services' significant net financial and environmental advantages.

3.8. Hostile land tenure systems

Land tenure generally refers to a system of land-use rights and legally acceptable institutions that regulate access to land and eventually land-use [55]. Therefore, land tenure systems that are vague, casual, or overlapping do constrain individuals' investments in sustainable water and soil management (which includes CS-IPM innovations). For instance, customary land tenure systems usually present barriers to the implementation of CS-IPM innovations [20]. These barriers may include one's shorter duration of access and user rights to land, yet CSA in general including CS-IPM practices usually require long-standing investments in soil fertility and land resources' sustainability in general. Therefore, clear, and long-standing individual farm households' access and proper user land rights would foster such continuous and long-standing investments, thus effectively enabling adoption and deployment of CS-IPM innovations [56, 57]. Therefore, investment in improved CS-IPM necessitates protected land tenure systems as a precondition to continuous and significant investments in climate change feasible adaptations and thus CS-IPM innovations related to water and land management [56]. For example, in Uganda's Mubuku irrigation scheme, Ngigi [32] found that there was the rampant withdrawal of development partners from the support of the scheme, because of land tenure systems that were insecure. Insecure land tenure would condemn renting smallholder farmers to restricted land-use rights, thus having minimal authority on their favorable investment decisions on the land.

3.9. Cultural limitations

Cultural values avail both opportunities as well as barriers on communities' acceptance, adoption, and diffusion of innovations including CS-IPM ones. For instance, Nielsen and Reenberg [58] in their study of two comparable ethnic groups in Burkina Faso, the Fulbe and Rimaiibe discovered that the Rimaiibe easily accepted diversifications in their livelihood approaches to adjust to climate change, however, the Fulbe instead found the same approaches unacceptable. Such insights throw a light on how societal culture may render certain adaptive approaches to climate change impractical even though these have been acceptable in other cultures. Therefore, understanding well the context of the local cultural, is valuable for successful deployment of CS-IPM innovations. Discussions about cultural practices and beliefs also is thus essential [58]. This is because, there is a necessity to study the behavioral, institutional, and cultural barriers to consider their complementarity with the proposed innovations [6, 15]. Smallholder agriculture in SSA is a "way of life" within which several cultural practices, norms, and beliefs, are an important life aspect in these communities [58]. Culture, beliefs, and behavior govern individuals' actions, acceptable practices, privileges, and rights in food production, distribution, and consumption activities, thus must be considered in the deployment of CS-IPM innovations. However, certain cultural activities like belonging to social groups instead boost knowledge acquisition and sharing thus fostering adoption and deployment of CS-IPM [6, 15]. Nevertheless, many including inadequate access to monies especially for women, yet costs are incurred in the deployment of CS-IPM hinders CS-IPM deployment [11].

3.10. Gender inequalities

In terms of gender dimensions, women's role in agriculture in Benin, Ghana, and the rest of SSA is substantial. For instance, in Benin, women make up to 35 percent of employment in agriculture and 14 percent of agricultural households are led by women [54]. However, despite their contributions to the sector, women experience several challenges in water and land use including restricted land access and user rights, again due to cultural customs [59]. Moreover, women also face more obstacles than men in accessing improved inputs, agricultural production technology, land, education and extension services, and finance, that are all essential in deployment of CS-IPM innovations [12, 59, 60, 61, 62]. The shortage of productive capital to women lessens this proportion of farmers' capacity to deal with adverse climate impacts, and thus deployment of CS-IPM innovations [63]. Therefore, gender issues can form the required background for prioritization and adoption, and deployment of CS-IPM technologies, practices, and services. For instance, in Lesotho, females who modify farmlands that they are not culturally permitted to possess, may lose these farms to that are usually redistributed to their masculine relatives [62]. Furthermore, in some parts of Ghana, women can only access lesser land for agriculture which renders trying new innovations riskier CS-IPM innovations whose outcomes may not yet be confirmed [56]. Therefore, gender-responsive planning is critical for the success of innovations including CS-IPM [64].

3.11. Knowledge on CS-IPM practices

An integrated effective approach to controlling pests intensively requires good technical awareness and knowledge which usually necessitates continuous monitoring thus rendering the approach more expensive with multiple indirect costs, unlike the plain usage of pesticides. Therefore, technical awareness and advocacy aimed at promoting CS-IPM innovations and the concept at large is indispensable and can only be achieved through an effective knowledge transfer process [32, 65]. For example, deficiencies in knowledge have been found to be key impediments to innovations uptake among Ghana's farming households [29]. Unfortunately, most farm households in Africa either lack proper access to knowledge or sometimes are unable to utilize effectively existing knowledge [65]. Moreover, successful, and useful adaptation to innovations necessitates the need have sufficient knowledge about existing alternatives of the innovations to be

adapted, the technical ability to evaluate these alternatives, and subsequently the technical capability to select contextually suitable alternatives for implementation [66, 67]. With regards to climate change, the need for knowledge can be revealed through acquisition and diffusion of appropriate information for instance on weather hazards, diseases, and pests. Lack of knowledge on CS-IPM due to low technical and logistical capacity of rural extension agents, impedes creation of awareness on CS-IPM innovations, and removes any incentives to deserving farmers to adopt CS-IPM [14, 67]. Lack of CS-IPM knowledge has instead, increased pesticide application as the principal strategy against climate induced pests [20, 68, 69]. Moreover, proper knowledge improves the identification of new and invasive pests' species and allow the good predictive ability for appropriate CS-IPM innovations against emerging pests' species, regarding geographic areas, and crops. Proper knowledge has for instance allowed effective control of the invasive fall armyworm [70, 71].

Therefore, overall knowledge processes for a successful operationalization of climate smart IPM include but not limited to the following elements:

- Climate-informed models of pest risks and candidate natural enemies, forecasting and monitoring, technical advisory extension services and protocols, and priority re-setting of management alternatives [72, 73, 74].
- Timely detection of invasive species and preventive action against future climate-risk pests.

This implies the need for an efficient implementation support strategy and partnerships:

- Enhancing governmental pest management front agents, farmers and other next- and end-users' capabilities in reporting, anticipation, proactiveness and response.
- Finetuning pilot evidence-based innovations and fostering the use of digital tools including Apps-led pest scouting and warning devices.
- Co-creating business models for pest management services and engaging private sector for sustainable deployment of impactful products and tools by empowering champion youth and women.
- Policy makers engagement to trigger legislative enabling environment and coercive measures for example against abusive/misuse of chemicals and particularly those prohibited and of high toxicity nature and having significant non-target effects.
- Accelerate the co-development and coordination of functional local and regional early warning and rapid response systems.

However, these knowledge processes components must be hinged on an efficient regulatory system that timely phases out Highly Hazardous Pesticides (HHPs) and active ingredients that pests have developed resistance to [72, 73, 74].

3.12. *Extension services systems' infrastructure*

Increasing demand and limited resources have put an enormous strain on much of SSA's extension services infrastructure leading to a degradation of their services. Yet, an appropriate, effective, responsive, accessible, and well-informed extension system is indispensable for supporting farmers to a successful adoption and implementation of CS-IPM. Conversely, extension services systems in many developing countries are deficient of these features hence limiting farmer's adoption of CS-IPM [14]. These deficiencies are due to illiteracy of extension agents about climate change, limited funding, lack of sufficient qualified personnel to deliver the extension services, poor coordination among key stakeholders for a given innovation for instance farmers, researchers, policy makers, extension agents, and remote localities of farm households [14, 69, 75, 76, 77]. Remarkably, weather centered advisory extension services already occurring for various pests [78, 79], although their employment in developing countries remains challenging. Therefore, improved communication between countries and regions is desired, to implement applicable

CS-IPM practices at regional level to effectively contain possible pests' outbreaks [45, 80]. Moreover, about 70% of the predicted climate possibilities for the future are already alleged to be occurring on earth in some places, thus adjusting a 'climate analogues' method spearheaded by CGIAR is contextually valuable [81, 82]. Therefore, escalating this method or approach to include pests would be pivotal to understanding what species of pests could be challenging for crops, and localities, cropping patterns, and henceforth informing appropriate changes in extension services systems [83]. However, extension services would require robust connections to reliable diagnostic services to guarantee that pests diagnoses done in the field are as accurate for appropriate recommendations [14, 79, 84, 85], and that CSATs including CS-IPM practices are optimally applicable [86, 87, 89, 90, 91, 92, 93, 94, 95]. In a nutshell, we clearly identify several central social-economic determinants for the deployment of CS-IPM practices as above, and we highlight some of these key factors in Table 1.

Table 1. Summary of some of the Key Studies Reviewed.

Reference	Country	Sample size	Data type	KEY CSA – IPM studied	Summary of key findings	Analytical Method used
Sain et al. [11]	Guatemala	42 CSATs stakeholders and 200 farms.	Survey Data	Pest and disease tolerant variety.	<ul style="list-style-type: none"> The CSATs analyzed are profitable except stone barriers. Cost and benefit analysis of CSATs mainly concerned the implementation of selected CSATs. The practice largely requires 4 to 9 years to generate economic gains. 	Mixed
Chhetri et al. [3]	India	16 villages in 4 diverse rainfall zones	Survey data.	Rainwater harvesting and storage.	<ul style="list-style-type: none"> The farmers' age significantly affects the grading of CSATs. Female farmers prefer integrated pest management, weather-centered crop advisories services, and contingent crop management compared to males. The results showed that farmers' preference for CSATs significantly differs according to rainfall zones. 	Mixed.
Shirsath et al. [89]	Bihar-North-Eastern India.	194 land units from 34 zones.	Survey data.	Seed replacement.	<ul style="list-style-type: none"> Input intensification as well as CSATs in current and future climate. Present technologies will not be climate-smart for the coming years. Even though present land-use practices will not be climate-smart for the future, novel technological intercessions will aid abate their negative impact. 	Spread sheet-based methodology.
Atitianti et al. [1]	Ghana.	80 Households.	Survey data	Using uprooted weeds and other biomass for mulching cleared lands.	<ul style="list-style-type: none"> Higher financial capital for CSATs farmers in their average incomes as compared to conventional farmers. Farm tenure determines CSATs practices. Increasing farmers' age (to a given threshold), was associated to increased adoption of CSATs practices. 	Mixed method.

Anuga et al. [9]	Ghana	320 smallholder farmers.	Survey data.	Mulching to avoid excessive use of water.	<ul style="list-style-type: none"> Social and cultural factors strongly influence CSATs' adoption by farmers. Institutional factors positively predict CSATs adoption. Personal aspects do not influence adoption of CSATs. 	Mixed method.
Zakaria et al. [6]	Ghana	543 Rice farmers.	Quantitative.	Improved seed use. (Drought-tolerant rice)	<ul style="list-style-type: none"> Farmers that have off-farm opportunities are more likely to accept CSATs. Farmers that have small farm sizes would accept CSATs if costs are minimal. Access to in-pup credit besides engagement in contract farming and production credit influenced the adoption of CSATs. 	Mixed using Quantitative Multivariate Probit Model.
Heeb et al. [14]	No specific country.		Descriptive	Pest populations could be prevented by applying multiple pest preventing methods.	<ul style="list-style-type: none"> CSA-IPM must broadly be addressed at all levels other than doing so only at farm level but in coordination with evidence-based policies. There should be assessment, selection, and evaluation of identified CSA-IPM options at all levels. 	Review.
Issahaku et al. [42]	Ghana	476 households.	Survey	Drought tolerant and early maturing varieties.	<ul style="list-style-type: none"> CSATs adoption significantly improves nutrition and food security. The impact of adoption differs across quartiles of nutrition and food security outcomes, and agro-ecological zones. Proper understanding of the drivers of CSATs' adoption improves the designing and diffusion strategies of CSATs thus increasing CSAT's adoption. 	Mixed and also using Endogenous switching regression.
Issahaku et al. [43]	Ghana.	476 households.	Survey	Crop choice.	<ul style="list-style-type: none"> Household characteristics and endowments influence household decisions to adopt CSATs. Access to inputs, herbicides and fertilizers positively influences households' execution CSATs. Herbicide's usage is gaining in importance for Ghanaian smallholder farm households. 	Mixed
Krishna et al. [86]	Ethiopia.	380 households.	Survey data	Change of crop variety.	<ul style="list-style-type: none"> Smallholder farmers' access to affordable credit services is key for CSAT's adoptability. Protected land-use rights are significantly motivated investments in viable CSATs adoption. The off-farm income positively influences the decision of smallholder households to adopt CSATs. 	Mixed. Used primary and secondary sources of data .

Kangogo et al. [21]	Kenya.	792 potato farmers.	Survey data.	Irrigation.	<ul style="list-style-type: none"> Adoption of all CSATs remains low and stands at only 45% in developing countries. There is also interdependence between practices for example certified seed and irrigation extra. CSATs that require intensive skills and financial investments are associated with risk-taking among farmers. Access to credit positively influences SCATs adoption, but only 15% of smallholder farmers do have access to agricultural credit. 	Mixed.
Zakaria et al. [15]	Ghana.	300 farmers	Survey data	Changing planting periods.	<ul style="list-style-type: none"> Only 11% of farmers do insure their crops against uncertainties despite farm insurance being introduced. Averagely, smallholder farmers accept up to around five CSATs practices to improve agricultural production and productivity. 	Mixed
Chanana et al. [12]	India	375 households.	Survey data	Change sowing dates.	<ul style="list-style-type: none"> Gender disaggregated data is so important in prioritizing and deploying CSA innovations, technologies, and practices. Supportive institutions are central in realization of gender-sensitive implementation of CSATs. 	Mixed
Christie et al. [10]	Ghana and Mali	293 respondents survey	Survey data	Pesticides use.	<ul style="list-style-type: none"> Gender-inclusive designs are strongly associated to good in Ghana and Mali Men are usually in charge of applications of pesticides on farms. Use of synthetic pesticides was the most single control practice used by farmers. 	Mixed method.
Houngbo et al. [67]	Benin.	1237 maize farmers.	National survey data.	Single cropping in rotation with other crops.	<ul style="list-style-type: none"> Neem leaves or seeds are used to locally produce botanical pesticides by smallholder farmers. Management practices exhibited by farmers are importantly e significantly related to farmers' knowledge of managing pests. 	National survey on maize farmers.
Loko et al. [65].	Benin	83 producers of Kersting's groundnuts.	Survey data.	Use of chemicals.	<ul style="list-style-type: none"> The attack of insects was the most devastating of the four storage constraints identified. Promotion of Kersting's groundnuts varieties can help minimize storage constraints. The palatability of stored Kersting's groundnut seeds attract attacks from insect pests. 	Mixed

Ratnadass & Deguine [7].	No specific country	Not mentioned.	Review data	Use of Synthetic insecticides and rodenticides.	<ul style="list-style-type: none"> • Crop protection practices in the paper were applied mainly to pests. • Agroecosystem redesign is the most appropriate that is likely to foster enhancement of the One Health Notion. • The Agroecological Crop Protection framework addresses major global challenges like Climate resilience among others. 	Review methodology.
Makate [47]	Sub-Saharan Africa	Not indicated	Review data	Use of small-scale irrigation.	<ul style="list-style-type: none"> • The approaches or strategies identified must boost innovative technologies in agriculture include the climate-smart village approach extra. • Better markets and market information access positively drive demand upwards for CSATs like CS-IPM thus promoting adoption of CSATs. • Functional institutions and good policies are central to successful scaling of CSATs. 	Institutional analysis and development (IAD) Framework method.
Egan et al. [4]	Sub-Saharan Africa	Not mentioned	Review data	Host plant resistance and tolerance.	<ul style="list-style-type: none"> • Practical implementation of Climate Smart IPM requires; climate-informed advisory services, • Participatory Research for CS-IPM, And Policy Development. 	Technical Reporting.

5. Conclusions

In this review, we try to understand socio-economic factors that determine the adoption, implementation, and successful deployment of CS-IPM technologies and practices. Generally, adoption of climate-smart innovations, practices, and innovations that enable an ecological and sustainable management of pests in low, with most farmers relying on more and more use of pesticides as the major option against pests' populations that are climate induced or otherwise. The more frequently stressed factors that deter immediate and extensive adoption of sustainable CS-IPM innovations are largely farm-level issues that include the gender, education level, and age of household heads, household farm size, income, access to markets and finance, and location. However, institutional barriers like lack of appropriate extension services, poor research infrastructure, and antagonizing policy frameworks do also persistently frustrate and fail adoption of CS-IPM innovations and CSA in general. Addressing these factors concurrently, therefore, would significantly pave a clear way for willing farm households to adopt CS-IPM innovations, thus fostering a more sustainable and extensive scaling of multiple CS-IPM practices. Hence, a clear approach that harmonizes and conveys together recognized CS-IPM practices and tools with a robust emphasis on adjusting these tools and practices to all changes that are climate-induced while prioritizing pests, is very crucial for successful and scaled adoption and implementation of CSATs and CS-IPM. Therefore, this approach will require a multi-stakeholder platform strategy that involves public support, and political leadership that is embedded within a favorable enabling CS-IPM implementing environment. Without proper coordination of the several stakeholders needed for effective adoption of innovations, the large-scale uptake of novel and appropriate pest management innovations, practices, methods, approaches, and technologies will only yield inefficient and vastly unsuccessful efforts of CS-IPM deployment. Moreover, CS-IPM is a dynamic and an ever-evolving approach responding to changes in climate. Therefore, continuous monitoring and

evaluation of activities and interactions of all stakeholders are required to assess and appropriately guide the execution of CS-IPM interventions, and their impacts. Such assessment enables continuous re-evaluation of the tools, practices, and approaches for selection of those that suit the given context best. Similarly, effective communication on pest pressures through data sharing between national and international institutions is pivotal not only in enhancing knowledge on the implementation of appropriate CS-IPM practices but also to foster connection across nature-based solutions, and CS-IPM deployment. However, the CS-IPM implementation process should be bottom-up, which employs participatory prioritization based on farmers' indicators, but also appropriate to the bio-physical and socio-economic context.

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