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Policy incentives for smallholder adoption of climate-smart agricultural practices

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There is a large and growing literature on the potential use of policy instruments for stimulating the adoption of Climate-Smart Agriculture (CSA) practices amongst smallholders. The objective of this article is to review and understand how the array of potential policy incentives can serve as mechanisms for enhancing adoption and upscaling of potential CSA practices by small-scale farmers in low-income countries. The review follows a matrix approach capturing where specific CSA practices (rows) are supported by typical policy instruments (columns) for enhancing widespread adoption. We first identify six key CSA practices, namely water management, soil and nutrient management, crop tolerance to stress, agroforestry and intercropping, crop rotation and mixed systems, and pest and disease management. Then we discuss the impact of those typical policy instruments, namely market prices, taxes and subsidies, land rights, rural finance, training and information, and certification and labeling. The review finds that most studies on this subject have a rather narrow focus on functional properties of a specific policy instrument and a particular CSA practice, thereby ignoring substitution, complementary or conditional effects between policy measures and CSA practices. Consequently, previous studies identify few incentives, particularly effective on their own. Wider perspectives on impact pathways point to the importance of sequencing and scaling for enhancing farmers' CSA adoption. We therefore advocate for more integrated approaches that also consider indirect effects of policy instruments on CSA adoption and pursue their systematic anchoring through successful policies that enhance widespread adoption.

KEYWORDS

climate-smart agricultural practices, adoption, smallholder, incentives, policies

1. Introduction

Climate-Smart Agriculture (CSA) is an approach to change agricultural production to improve food security while addressing challenges that climate change brings (Lipper et al., 2014). The approach promotes technologies that increase factor productivity, promote farmers' resilience to related climate hazards and risks and contribute to climate change mitigation at regional scale. It builds upon three pillars: (a) increase of agricultural productivity (yields) and incomes, (b) adapt and build resilience to climate change within the agricultural systems, and (c) reduce greenhouse gas emissions when possible (Rosenstock et al., 2015).

Under the Paris Agreement on Climate Change Agreement, parties are required to engage in adaptation planning processes and building the resilience of socioeconomic systems, which obviously also include agricultural policies (Verschuuren, 2016). Many countries have embraced the concept of CSA and submitted Intended Nationally Determined Contributions (INDCs) specifically referenced CSA. Countries endorse or prioritize actions intended to harness the potential synergies between mitigation and adaptation in agriculture (FAO, 2017). Through research cooperation, the knowledge base underpinning CSA has also grown significantly. The insights gained in recent years from empirical field experiences have created a better understanding of potential accelerators and barriers to the adoption of CSA practices. Such analyses are essential for preparing the ground for the further expansion of CSA at all levels. In addition, there is an increasing demand for better understanding the possibilities to support CSA adoption through socio-economic policies and incentives, and for suitable tools to make ex-ante assessments of the likelihood of adoption of CSA practices at household and (sub)regional level.

Adoption of CSA technologies by smallholders requires that those farmers consider these practices suitable for their purposes and resources, and contributing to their livelihood preferences. This mean that different farmers could also respond differently to opportunities for adopting CSA technologies (Andrieu et al., 2017; Khatri-Chhetri et al., 2017; Mwongera et al., 2017), and there might even be conflicts within households regarding their suitability for gender empowerment (Howland et al., 2019). Notwithstanding this diversity of responses, and in line with the differentiation of farming opportunities and strategies, we can identify some CSA practices that are widely appreciated by rural households because they deliver tangible outcomes with a high degree of certainty and face limited resource constraints for their adoption. However, as Chandra et al. (2018) have also argued, there is a need to identify social, management, and economic factors that influence the implementation of CSA approach in low-income countries.

The main purpose of this article is to identify effective policy incentives that support CSA adoption by vulnerable farmers in low-income countries, and to understand how these incentives contribute to farm-household livelihood strategies, in such a way that benefits are realized in terms of higher factor rewards, improved household welfare and better resilience. Particularly, we focus on two research questions: (a) how does the resource intensity of CSA practices influence the likelihood of their adoption by smallholder farmers in developing countries? and (b) which types of external incentives contribute to enhance the responsiveness of smallholder farmers toward wider adoption of CSA practices?

This analysis provides insights in the range of possible policy measures that are effective to be used for speeding-up and/or spreading the adoption of suitable CSA practices by larger segments of farmers. We review typical empirical studies from the literature on selected CSA practices that provides robust testing of the outcomes of some key policy incentives for CSA adoption. The article tries to link knowledge regarding farm households' demand-side constraints for CSA adoption to empirical evidence about effective leverage points for enhancing adoption from the supply-side. It thus addresses existing knowledge gaps concerning differences in adoption intensity of CSA practices and contributes to the theory of motivation that considers the impact of extrinsic incentives on the adoption of innovations in line with the intrinsic behavioral drivers and resource endowments of stakeholders (Roumania et al., 2015; Piñeiro et al., 2020).

The remainder of this article is structured as follows. Section 2 outlines the analytical framework for linking a range of selected CSA practices to a set of potential policy instruments. Section 3 summarizes the existing evidence on the effectiveness of policy instruments to support the adoption of CSA practices. Section 4 assesses the feasibility of different types of incentives to support the likelihood of adoption of CSA practices from the farmers' resource endowment and livelihood perspective. Section 5 gives a summary of the available evidence on the impact of specific policy incentives for CSA practice adoption, making use of a heat map to illustrate the strength of available evidence. Section 6 concludes with recommendation for CSA policy design and indicates knowledge gaps where further research is required.

2. Analytical framework

To assess the effectiveness and efficiency of market incentives for the promotion and adoption of CSA practices in primary production, we rely on an analytical framework that comprises three dimensions: (a) identification of key CSA practices that are used by farmers, (b) assessment of the resource use requirements of these CSA practices, and (c) overview of policy instruments that can be applied by public programs or development projects to stimulate the adoption of CSA practices.

CSA practices are incredibly diverse and reflect the context-specificity of opportunities, constraints and vulnerabilities. In our study we use CSA practices and CSA clusters that are identified by Sova et al. (2018) and are most used in sub-Sahara Africa to support the transition toward more resilient farming systems. Even while CSA is highly diverse, six technology clusters account for 55% of all CSA technologies as climate-smart across 33 countries (see Figure 1):

- water management (to reduce water stress and for dealing with irregular rainfall pattern),
- organic and inorganic inputs (e.g., improving soils with integrated nutrient management, mulching), hence referred to as soil and nutrient management,
- crop tolerance to multiple types of stress (more resilience due to drought -, flood -, pest and diseases–and saline-tolerant and/or early maturing crops),
- agroforestry and intercropping (including green manure, cover crops, aqua- and silviculture, etc.),
- crop rotation and mixed systems (diversification for nutrient recycling and resource efficiency),
- pest and disease management.

These CSA practices make different demands on farm-household resources, where some practices require more capital-, land- and/or labor inputs, and others depend on large scale production and/or need bigger size of market outlets for making their adoption feasible. The resource use intensity of specific CSA practices determines to a large extent whether smallholder farmers are able to fit them into their farming system and livelihood strategy.

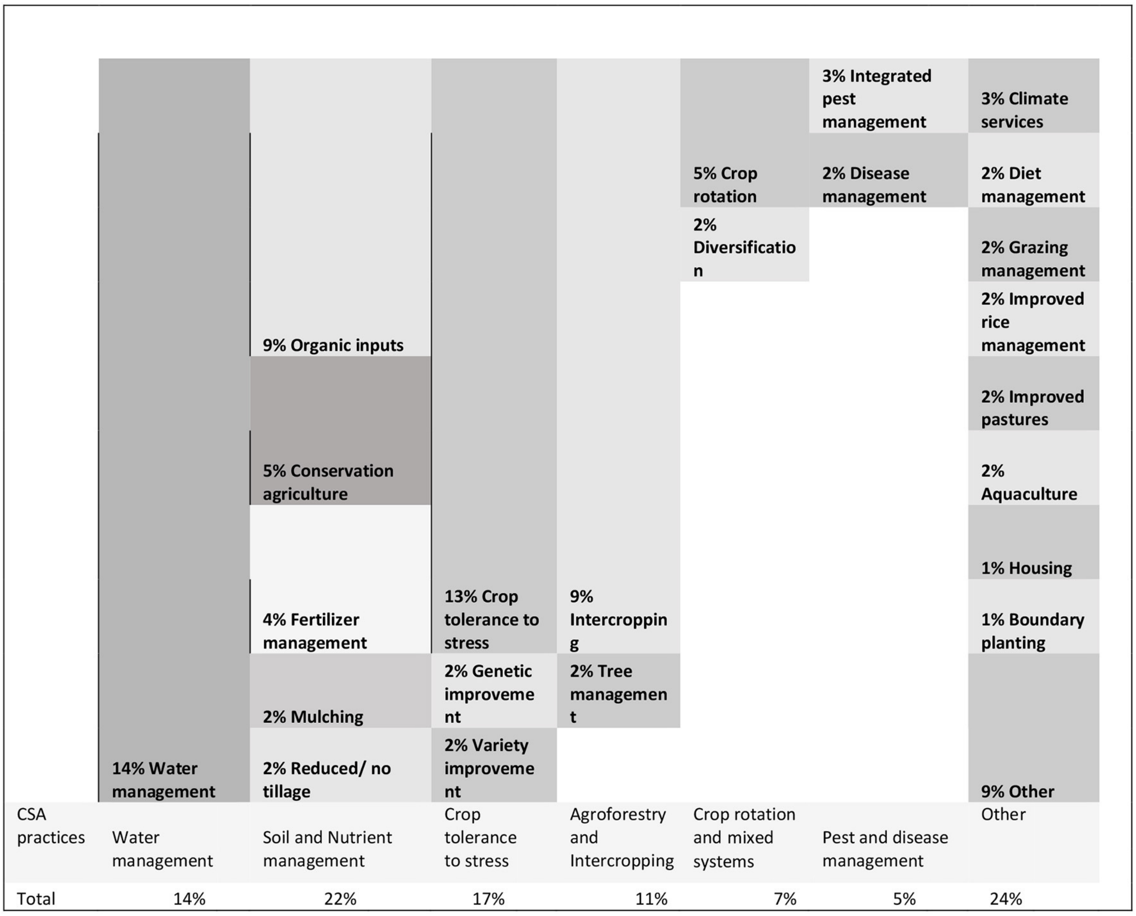

FIGURE 1
Frequency of use of CSA practices. Source: based on Sova et al. (2018).

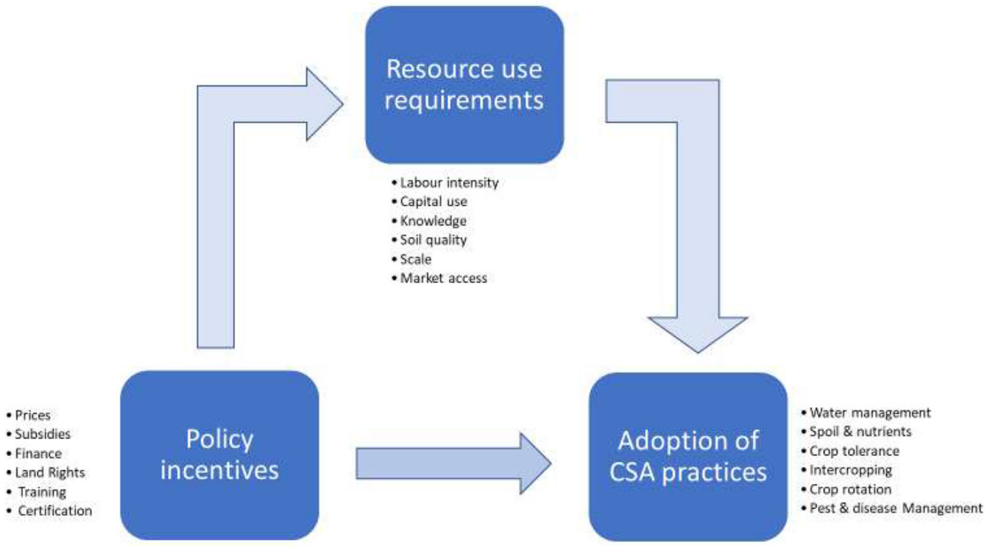

FIGURE 2
Linkages between policy incentives, resource requirements and CSA adoption.

TABLE 1 Policy incentives that may support adoption of different CSA practices[a].

Incentives → CSA practices ↓	Market prices	Taxes and subsidies	Land rights	Rural finance	Training and information	Certification and labeling
Water management	+	+	+		+	+
Soil and Nutrient management	+	+	+	+	+	+
Crop tolerance to stress				+	+	
Agroforestry and Intercropping	+		+	+	+	+
Crop rotation and Mixed systems	+		+	+	+	
Pest and Disease management	+	+		+	+	+

[a]"+": potential working sphere of the policy incentives for specific CSA practices.

TABLE 2 Resource requirement for different CSA practices[a].

Resource requirements → CSA practices ↓	Labor intensity	Capital investments	Knowledge	Soil quality	Scale	Location (market access)
Water management	+	+++	+	+++	+++	+++
Soil and nutrient management	++	++	++	++	+	+
Crop tolerance to stress		++	++	+	+	++
Agroforestry and intercropping	++		+			
Crop rotation and mixed systems	++	+	+++	+		+
Pest and disease management	+++	+	++	+	++	++

[a]"+", "++" and "+++" denotes some, average and substantial resource requirements respectively.

The feasibility of adoption of different farming systems practices can be influenced through a range of external policy incentives that:

- modify the costs and benefits structure of inputs/outputs (using prices, taxes and subsidies),
- reinforce the certainty for reaching expected revenue streams (through improved land rights),
- enable the intensification of farming systems (supply of credit),
- enhance farmers factor returns (through better knowledge on production), or
- improve marketing margins (from certification or labeling).

These incentives can be used to support farmers in shifting their resource allocation toward more resilient CSA practices. These decisions are usually guided by expected welfare motives, i.e., increased farm-household net revenues, higher net labor rewards and/or reduced exposure to risk (Trujillo-Barrera et al., 2016). The importance of these drivers may differ between marginal, small-scale and medium-size farmers, with the former giving more attention to risk mitigation and the latter to realizing higher net revenues. This reflects the different weights attached to short-term financial performance versus long-term viability of the farm.

The analytical framework used for the subsequent analyses in this article combines these three dimensions by (a) assessing the effectiveness of a range of potential policy incentives on (b) the resource use intensity requirements and market conditions for specific CSA practices, for (c) enhancing the likelihood of adoption of different CSA practices (see Figure 2).

We made an effort to identify evidence-based field studies that inform about interactions between policy incentives and farmer responses toward CSA adoption. Table 1 provides an overview of the hypotheses regarding the potential effects of policy incentives on the likelihood of adoption of different CSA practices.

We expect market price instruments to play a more prominent role in the adoption of resource-intensive practices, like improved water, soil and nutrient management (that increase input costs) as well as intercropping/crop rotation and pest management (that tend to increase labor use). In a similar vein, taxes and subsidies are most relevant for capital-intensive CSA practices (including purchase of drought-tolerant seeds). Land rights are most relevant to support the adoption of more capital-intensive CSA practices (water and nutrient management) and for CSA practices that need a longer maturation period (agroforestry and crop rotation). The same holds true for rural finance facilities, that are also relevant for application of pest and disease management practices. Training and information incentives are considered relevant as incentive for adoption almost all CSA practices, whereas certification only provides returns for CSA practices that create identifiable product-related sustainability characteristics.

Within these two dimensions, we will identify how much robust empirical evidence is available that informs about feasible impact pathways. These are mediated by (a) the (individual and communal) factors that influence the likelihood of CSA adoption, (b) the behavioral responses that shape smallholder perceptions

TABLE 3 Heat map of incentives for CSA practice adoption[a].

Incentives → CSA practices ↓	Pricing		Access		Upgrading	
	Market prices	Taxes and subsidies	Land rights	Rural finance	Training and information	Certification and labeling
Water management						
Soil and nutrient management						
Crop tolerance to stress						
Agroforestry and Intercropping						
Crop rotation and mixed systems						
Pest and disease management			n.d.			
N (number of cases)	15	12	6	20	9	5

[a]Share of cases per policy instrument that report on CSA adoption (cases can comprise multiple incentives and practices). n.d = no data.

Low		Medium		High
0-20 %	20-40%	40-60%	60-80%	80-100%

regarding the benefits and risks of technical change, and (c) the contextual variables that support food system transitions at scale (and eventually also generate general equilibrium price effects on the market).

For the careful assessment of scope and influence of each of the different policy instrument in shaping smallholder CSA adoption opportunities, it is also important to distinguish between local (farm/field-level) studies that tend to focus on resource use efficiency, household-level and livelihood studies that address welfare effects from an effectiveness angle, and village-level landscape analyses that take resilience and sustainability into consideration. Policy incentives may generate different outcomes at each level, and therefore trade-offs between these dimensions deserve special consideration.

Finally, our overview is based on a wide scan of published field studies that rely on different research methods. Both field survey-based and experimental studies as well as model simulations are included, and data analyses are based on a diversity of quantitative and qualitative procedures for robust impact assessment. Due attention is given to the identification of specific local confounding factors that may have influenced CSA adoption.

3. Effectiveness of incentives for CSA adoption

In this section, we will provide a systematic overview of existing evidence with respect to the effectiveness of different policy instruments to support the adoption of CSA practices. We therefore discuss the main areas of influence for each of the six types of policy incentives and identify the underlying impact pathways that could explain farmers' responsiveness.

For the collection of relevant articles, we relied on Google Scholar for an initial search using as keywords: CSA practices, adoption, incentives, policies, low- and middle-income countries. Hereafter, we made a selection of the empirical studies that used robust measurement approaches (both statistical and experimental methods) and contain valid information on impact at farm-household level. More articles were found on the effectiveness of economic and financial incentives (i.e., finance, prices and taxes), whereas fewer cases looked at institutional and capacity development strategies (such as land rights, training and certification).

3.1. Market prices

Markets prices and market access conditions are an important drivers of CSA practice adoption (Steenwerth et al., 2014). CSA implementation is often dependent on affordable input markets for accessing seeds, fertilizers, irrigation, or other inputs they need. Moreover, functioning output markets with fair prices are required to pay for the inputs. At the same time, implementing CSA at scale can affect market prices through increasing productivity and improving climate resilience.

Many CSA practices require additional investments, so farmers getting higher and more stable market prices are generally more likely to adopt CSA. For example, in Northern Ghana, access to markets for farmers and the ability to sell their produce at adequate prices was required to cover costs of a new irrigation technology (Akrofi et al., 2019). Similarly, in the Senegal River Valley of Mauritania, farmers can grow climate-smart sorghum and achieve higher profitability from a higher market price (and lower irrigation costs), despite lower yields, as compared with rice (Garcia-Ponce et al., 2013). de Sousa et al. (2016) found that smallholder timber production in agroforestry systems received lower market prices than timber from forests due to lower quality and inferior building capacity. On the other hand, Central American smallholder agroforestry farmers with improved silvicultural practices could improve the quality of their timber and sell at 58% higher prices in the market.

Being in the proximity to input and output markets is generally found to promote adoption of CSA practices. In Malawi, the distance farmers traveled to markets affected the likelihood of adopting small-scale irrigation (Mango et al., 2018): every one kilometer increase in the distance to an input or output market resulted in a 18% decreased adoption of irrigation. Similarly in Ethiopia, the share of irrigated land depends on distance to market, ease of selling output, age, aridity, distance from natural water sources, credit access, and regional differences (Wakeyo and Gardebroek, 2017).

Not only are prices and access to markets important, but market price stability/volatility is also an important factor driving farmer's adoption decisions. Indian cotton farmers prone to pests and diseases and high price fluctuations switched to the high-yielding variety (HYV) chickpea, which is a lower risk crop for the dry agro-climatic conditions where they farm (Reddy et al., 2016). This HYV chickpea reduced the costs of production, enhancing competitiveness with competing crops and lowering farmer upfront investment given price uncertainty. Implementing CSA can also help to stabilize markets, for example drought tolerant maize has the potential to stabilize yields across years, reducing risk for farmers (Birthal et al., 2012). Price volatility of inputs is also an issue impacting the adoption of CSA; TerAvest et al. (2019) found that for adoption of diverse crop rotations in Malawi, policies are needed to reduce input price variability and increase farm-gate prices of alternative food crops.

Market prices affect the payback period for investments in CSA, helping to incentive or disincentive CSA investments that take time to recover upfront investment costs. Some CSA investments, such as terraces on moderate and steep slopes can increase yields and income, but were found to have to be maintained for at least seven years to result in significant increases in value of production given market prices (Schmidt et al., 2017). For a payback period of this length, such investments generally require means to incentivize adoption and long-term maintenance (e.g., subsidies or paired infrastructure investments).

The bottom line is that if prices prevent healthy margins, adopting better practices might not pay off. Price signals and improved access to market services have been shown to increase farmers demand for both inorganic fertilizers and soil amendments (Kamau et al., 2014), however, if output market prices are not sufficiently high, adopting such improved management practices were found to lead even to a decrease in profitability. In Zambia, higher fertilization rates were shown to be marginally profitable or unprofitable under common agronomic practices, with current commercial fertilizer and maize prices (Burke et al., 2017). In this case, other inputs and training in agronomic practices that raise crop response to fertilizer would be needed for it to become profitable for farmers to invest in more fertilizer. And this should be tailored and targeted at specific microclimates and soil types that are more likely to result in higher crop response to fertilizer application.

Ultimately, market prices and price volatility must align with the farmer's risk tolerance and bottom line profit margin for farmers to adopt CSA interventions, although other incentives can also play a role, particularly when markets are not providing a strong enough signal and incentive.

3.2. Taxes and subsidies

In general, to encourage climate change mitigation or adaptation efforts, public policies may take the form of taxing externalities on either inputs that generate pollution, or greenhouse gas outputs (i.e., carbon tax), or subsidy payments to encourage adoption of desirable production techniques. Often, these taxes and subsidies are in combination with other regulatory restrictions and voluntary actions (Balasubramanya and Wichelns, 2012).

Currently, most attention is given to enhance the local adaptive capacity of farming systems, since for mitigation usually more global and long-term mechanisms are required. Taxing smallholders directly, or indirectly by upstream or downstream actors in the agricultural value chain, will most likely adversely affect the poor and vulnerable smallholders. Mitigation of greenhouse gas commonly faces an essential problem that private returns are commonly negative for smallholders (Ruben et al., 2018).

Subsidies can be justified for positive externalities or under specific circumstances, for example when there are strong learning-by-doing effects or for innovations with large transformative impacts (Gautam, 2015). To overcome poverty, out of which risk-averse smallholders are trapped in a vicious circle of low investment leading to low productivity, frequently the case is made to rationalize agricultural input subsidy policies. The current wave of agricultural input subsidy policies mostly focuses on mineral fertilizer and seed, but regional differences in targeted inputs are observed (Rashid et al., 2013). Often input subsidy policies in areas with very low nutrient loads, quickly raise national food production, and beneficiary households raise crop yields and improve soil fertility, at least in the short-term (Jayne et al., 2018; Scholz and Geissler, 2018). Most input subsidies policies are primarily designed to address food security issues, and in general remain one of the most contentiously debated development issues (Jayne et al., 2018). For example, they partially crowd out commercial (fertilizer) demand, or even become an environmental risk factor (Scholz and Geissler, 2018). To a much lesser extent input subsidy policies encouraged climate change mitigation and adaptation efforts in the past, but are emerging rapidly. A typical example are subsidies for drought tolerant seed in Malawi, a technology that holds considerable promise for helping smallholder to adapt to drought risk. The Malawi Farm Input Subsidy Program was the main driver a substantially increase in adoption. Subsequently, experienced drought and farmer risk aversion stimulated adoption furthermore (Holden and Fisher, 2015). In general, the ultimate policy objective should be that, after a limited period with public intervention, adoption of CSA practices will upscale in the private market.

Also more lumpy CSA investments are of interest for public support, of which the promotion of irrigation techniques is a typical example. In Asia developing irrigation has been central to the green revolution. Typically, initial investments (e.g., dam diversion structure and canal systems) are generally paid by the government, but the operation and maintenance costs are shared jointly by the government and beneficiary farmers (Rashid et al., 2013). It is projected that Africa does not have the same irrigation potentials as Asia, but irrigation expansion can be done with very high returns (You et al., 2011).

There are numerous policy instruments that enable governments to intervene in the event of natural disasters, in particular various types of subsidized insurance schemes (with premium subsidies as used for example in the USA, many EU member states and India). Crop insurance is an effective financial instrument to adapt to climate change since farmers are indemnified in adverse times. Insurance-type policies could be tailored toward smallholder farmers to compensate agricultural producers for the profit losses if spending more on inputs for practicing CSA (Asci et al., 2015). Yet, in many developing countries premium support is absent, with some notable exceptions. For example, the Ugandan government subsidizes 30% of the premium for commercial farms and 50% for small-scale farms, rising up to 80% of the most disaster-prone districts, where premiums are higher. Basic premiums on all subsidized products are limited to 5% (10% in disaster-prone areas) to ensure affordable prices and adequate coverage, although farmers in higher-risk areas still have to bear part of the drought risk themselves (Van Asseldonk et al., 2018). Widespread adoption in developing countries hinges on the cooperation with aggregators as intermediaries, channeling brokerage services to a vast number of individual smallholders who would otherwise be too difficult to reach. Typically (drought) insurance is compulsory when bundled with credit and input supply, but such large-scale CSA linked crop insurance are not yet available.

3.3. Land rights

Registration of land rights is commonly used as a procedure for strengthening land administration, reinforcing land ownership feelings and reducing risk perceptions amongst smallholder farmers. Improving land rights is usually perceived as a device for encouraging farmers to become engaged in investments that contribute to more sustainable land use practices and reinforce farmer's adaptation to and mitigation against climate change (Ingram and Hong, 2011).

Land rights are considered of critical importance to support the process of sustainable land use intensification, dedicating resources to improved land and water management practices and in-depth investments in assets for land conservation (Montpellier Panel, 2013). Land titles are used to reinforce farmers' propensity to invest, to reduce their time discount rate and to increase perceived certainty. This is expected to enable higher investments in CSA practices and better diversification of cropping systems and household income sources that lead to increasing resilience against climate shocks.

The importance of land rights for adoption of CSA practices is further confirmed in several studies that identify land ownership as a positive force toward improving land management (Knowler and Bradshaw, 2007; Lawin and Tamini, 2018). This particularly holds for land-related investments in soil and water conservation, tree cropping and agroforestry systems, and more intensive permanently settled livestock rearing activities.[1] This tendency becomes even stronger if female land ownership is supported and effects of women empowerment is considered, that tends to give priority to more diversified cropping systems and leads to higher investments in child education and household asset creation (Salcedo-La Viña and Morarji, 2016). Consequently, rural households become more resilient to climate shocks and investment portfolios are better tailored toward CSA adaptation and mitigation strategies.

Climate change has been characterized as a "threat multiplier" that tends to aggravate human insecurity caused by local factors (like unsecure land rights and resource scarcity) and may contribute to sometimes violent socio-political conflicts that particularly occur in regions vulnerable to climate change. This provides the rationale for a broader appraisal of incentives for the adoption of CSA practices that consider multiple constraints in rights and endowments. Recent insight indicate that landscape approaches can be particularly helpful to support simultaneously both CSA adaptation and mitigation strategies that simultaneously reduce uncertainties at different system levels (Harvey et al., 2014).

3.4. Rural finance

Rural finance can affect adoption of CSA practices directly. Access to credit allows the farmer to choose adaptation strategies that require additional investments (e.g., larger doses of fertilizer, purchase of other seeds with a shorter gestation period) (Yegbemey et al., 2013). Credit financing does require the CSA practices to be profitable, in order to repay the loan and cover the credit risk.

There are also indirect CSA effects of rural finance. Access to credit, savings and insurance is a mechanism for risk management of farm households, smoothing consumption and stabilizing the household's resilience to climate events and other shocks. The functionality of this mechanism hinges on several enabling conditions, such as a sufficient income to repay the loan, land quality and interest rates. Another indirect effect of rural finance is its contribution to higher farm incomes. This can in turn lead to expenditure effects, including adoption of certain CSA practices (Ruben et al., 2018).

The effects of credit on the adoption of specific CSA practices has been investigated in several studies. The largest number of studies is found on the adoption of soil and nutrient management practices. Some studies find a positive effect of credit on a set of practices, mostly for practices that require cash liquidity (inorganic fertilizer, improved seeds) (Pender and Gebremedhin, 2008; FAO, 2016; Ndagijimana et al., 2019). But the effects are not in all cases significant (Di Falco et al., 2012; Rosenstock et al., 2015), which may indicate the context-specificity of the factors constraining adoption. In some studies credit–especially fertilizer loans–enhances the use of mineral fertilizer, but this can partly substitute organic forms of fertilization (Bellwood-Howard and Al-Hassan, 2016) or

1 For instance Kpadonou et al. (2017) show that adoption of soil and water conservation technologies in West African Sahel is positively related to land holding and tenure of farmers.

other soil improvement measures with longer-term benefits like intercropping (FAO, 2016).

The effect of credit on adoption of CSA practices may work out differently for women than for men, as access to credit and cash is unequal for men and women (Wong, 2016). Also differences between farmers' risk preferences play a role (Marenya et al., 2014), as well as differences in farmers' general socioeconomic status (Kassahun and Jacobsen, 2015). Adaptation of credit features to specific target groups and users is therefore crucial (Peck Christen and Anderson, 2013).

The effects of credit on other practices is less investigated, although some studies can be found. Access to credit can have a positive effect on the adoption of water harvesting and supplementary irrigation technology (He et al., 2007). Also other water management systems at farm level are more easily adopted when credit is available, for example tied ridges–with credit for labor (Mutua-Mutuku et al., 2017)–or groundwater motor pumps (Owusu et al., 2013). Some indications are available that credit would also contribute to adoption of agroforestry, for example for timber trees because of the initial investments and the delayed revenues (Jacobi et al., 2017), and also for dual-purpose forages as hedgerow species (Lapar and Ehui, 2004). Adoption of crop rotation can be positively affected by access to loans, as shown in the case of alfalfa pasture–food crop rotation in China (He et al., 2008). Access to credit can accelerate the adoption-diffusion cycle of improved varieties (Lemessa, 2017).

Some studies have been conducted on the effects of crop insurance on adoption of CSA practices. Expansion of crop insurance may stimulate farmers to intensify their production, among others through irrigation, and this would increase the pressure of agriculture on scarce water resources (Deryugina and Konar, 2017). A rainfall index insurance may have a positive effect on the choice for soil conservation practices, but a cash incentive is more powerful, even if the expected return is lower than the insurance (Marenya et al., 2014). From another angle, crop insurance in itself is considered a climate adaption instrument, as it insures farmers from crop damages due to drought or excessive rainfall.

3.5. Training and information

Farmers may underinvest in a new (CSA) technology with high returns when the returns to technology are uncertain, or if they do not know how to apply the technology efficiently. Information (and training) on the new technologies are expected to reduce the uncertainties and provide the operational knowledge on the effective application of the technology, thereby changing the behavior of farmers toward the optimum decision-making for investing in the new technology (Foster and Rosenzweig, 1985, 2010).

Traditional economic theory suggests that access to the information on new technologies is costless. It is, however, usually opposite for small-scale farmers from developing countries due to their limited access to information and communication technologies, and the prevailing low education level among those farmers. Extension approaches have therefore been used as a mean of providing information on new farming technologies in developing countries since the 1960s. The main aim of the extension is to inform farmers about the costs and benefits of agricultural technologies and train them about how to manage those technologies. The extension service usually involves agricultural specialists who advise the farmers on various farming issues, including new technologies. The approach is implemented in many forms such as extension agent visits, farmer field schools (FFS), or training and visit (T&V).[2]

Few studies use rigorous empirical econometric and experimental methods to investigate the impact of information provision through extension approach on the adoption of CSA technologies. Few studies identify that extension services have been successful in improving the knowledge required for the adoption of water management, crop rotation, and soil and fertility management technologies. For instance, Pan et al. (2018) examine the impact of a large-scale agricultural extension program for smallholder women on technology adoption and food security in Uganda. They document that the farmers from the villages that are covered by the program are more likely to use manure, irrigation, intercropping, and crop rotation techniques when compared to those from villages that are not covered; thereby improving the food security among household farmer. In the same vein, Lambrecht (2014) find that extension programs are positively associated with the use of mineral fertilizer among the small-scale farmers in eastern Democratic Republic of Congo. Tambo and Abdoulaye (2012) show that contact with extension services is positively related to the adoption of drought tolerant maize in rural Nigeria.

Specifically, with regards to the impact of FFS, Tripp et al. (2005) examine the insecticide use of rice farmers in Sri Lanka and show that FFSs reduce the insecticide use among the participants of FFSs. However, the effect of FFSs on the insecticide use does not diffuse to the non-participants. Godtland et al. (2004) also evaluate the effect of FFSs on knowledge of integrated pest management in potato cultivation by using survey data from Peru and comparing with non-users through matching methods. They find that farmers from FFSs have more knowledge about the practices than those who are not joining FFSs. Martin and Taylor (1995) explored the impact of a T&V program implemented in Honduras and showed that participants of the T&V program are more likely to adopt seed spacing, fertilization practices, and weeding techniques when compared to non-participants.

Farmers traditionally learn farming practices from other fellow farmers through their social network. If social networks are effective, there is less need to upscale the extension services, as those services are expensive due to the high cost of hiring extension specialists and organizing many training sessions. Instead few farmers can be selected to the extension services, and those farmers can disseminate the information on the new technologies in their networks. The increasing number of studies, therefore, explore the role of learning from others and social networks as tools of agricultural technology dissemination. Those studies detect that social networks may have an important influence on the adoption of agricultural technologies (Bandiera and Rasul, 2006;

2 Please see the detailed discussion at Aker (2011) on this.

Conley and Udry, 2010; Munshi, 2004; Moser and Barrett, 2006; Foster and Rosenzweig, 2010; Maertens and Barrett, 2012).

To our knowledge, few studies investigate how useful information, specifically about CSA technologies diffuses through social networks through learning from others. Some of these sparse studies, however, reach promising results, suggesting that learning from others can upscale the adoption of CSA technologies. In one of those studies, Nakano et al. (2018) investigate the dissemination of technology diffusion through training key farmers among smallholder rice producers within rural irrigation scheme in Tanzania. They compare the adoption of technologies by key farmers with intermediate farmers trained by key farmers and with ordinary farmers and find that key farmers are more likely to use the technique of transplanting in rows and mineral fertilizers, which improves the rice yields. Krishnan and Patnam (2014) use data from Ethiopia from 1999 to 2009 to examine and compare the effect of extension services and learning from neighbors on the adoption of improved seeds and fertilizers. They identify the positive impact of both. The effects of extension services was high in the early stages of the introduction of extension agents. The effect of extension agents disappeared after some years while the effect of learning from others remained effective over the years. Matuschke and Qaim (2009) examine the effect of social networks on the use of hybrid pearl millet and wheat seeds in India. They show that learning from other farmers enhances the use and adoption of those improved seeds.

Other findings suggest that extension approaches based on farmer field schools and horizontal learning from others contribute to the adoption (and adaptation) of some technologies in water management, soil and nutrient management, crop rotation and mixed systems, and pest and disease management. However, this evidence comes from a limited number of studies and therefore results should not be interpreted these results as fully conclusive. Moreover, extension is not a silver bullet that can boost adoption rates and it is also rather costly to implement. There is still large adoption gap in countries with large histories in public agricultural extension facilities such as Ethiopia, Kenya, Malawi, Mozambique, and Tanzania (Brown et al., 2017). Current shifts to private extension are unlikely to reach poorer segments of smallholder farmers that most need the adoption of CSA practices.

3.6. Certification and labeling

Several studies address the role of labeling and certification for increasing farmers' welfare and/or supporting improved sustainability of agricultural practices (see: International Trade Centre, 2016 for a summary). Oya et al. (2018) provide a comprehensive overview of the available evidence with respect to the contributions of voluntary standards and certification for supporting farmer income pathways. Most current certification schemes (such as Fair Trade, Utz, Rainforest Alliance, FSC and MSC) provide a bundle of incentives that may include capacity building and training for farmers and producers' organizations, as well as different types of market interventions such as guaranteed market outlets, price premiums and credit facilities. Based on a meta-analysis from some 180 field studies that provide quantitative and/or qualitative evidence, Oya et al. (2018) find some positive effects on prices and farmers' income from the sale of certified produce, whereas little to no benefits for wage workers are registered. However, no significant evidence is found that total household income improves with certification. This is likely to be caused by resource use substitution that lead to more (input and labor-) intensive production practices as well as a tendency toward overspecialization of farmers on certified export crops (Ruben, 2017).

The effectiveness of voluntary standards and certification for supporting the adoption of sustainable farming practices is reviewed by Petrokofsky and Jennings (2018). Most quantitative and qualitative evidence from 116 studies focussed on primary production of tropical commodities (mainly coffee and forestry). Impacts on improved health and community developments are most frequently reported, whereas commonly cited drivers of practice adoption are related to externally provided technical assistance, institutional strengthening (market access and cooperative development) or financial support (price premium and some pre-finance). Robust evidence of impact of specific incentives for the adoption of sustainability practices is still rather scarce. Most changes are registered in the areas of conservation agriculture and organic input use. However, these effects tend to spread easily to non-certified farmers due to copying behavior. On the other hand, there is consistent evidence that climate change may increase farmers' (yield and price) risks and requires substantial adaptations in land use practices (Wiebe et al., 2015).

In summary, voluntary labels may support CSA adoption particularly if premium prices are applied and technical assistance is provided. Typical CSA practices that can be supported through certification include organic pest and disease management, forest conservation (reducing greenhouse gas emissions), and–to a minor extent–improved water and nutrient management practices and climate-resilience farming systems. The latter are of key importance for enhancing climate-smart agriculture, but are still difficult to translate into reliable and recognizable product standards.

4. Feasibility of CSA practices

In this section we assess the feasibility of different CSA practices to support climate resilient farming system from the perspective of farmers. We therefore focus on resource use requirements (land, labor, capital), market and institutional conditions (access, location), and the knowledge intensity and economies of scale and scope for each of the key CSA practices.

Table 2 provides a general overview of the resource use requirements of different CSA practices. Since few real-time cost-benefit analysis are available and outcomes may be fairly site-specific, we need to rely on comparative studies that assess cost effectiveness in terms of input requirements and output conditions (Adesina et al., 2000; Steenwerth et al., 2014; USAID, 2016; Mwongera et al., 2017; Sain et al., 2017).

Most attention is given to land, labor and capital requirements that are critical for small-scale farmers. Most studies report on relative differences in resource use intensity for specific CSA practices and therefore the classification (with + for some, ++ for average and + + + for substantial resource use in Table 2) compares the resource use requirements between for different CSA practices (i.e., the vertical dimension by column) and cannot be used for directly comparing the relative resource use intensity of specific CSA practices (the horizontal dimension), However, the combination of practices that simultaneously make intensive use of the same scarce resources (such as capital investments, good soils and market access) is likely to be less feasible.

Several CSA practices are more labor-intensive and might compete with farmers' engagement in non- and off-farm activities (raising the shadow price of family labor). In a similar vein, some CSA practices require upfront capital investments (in equipment) or operating costs (inputs purchase). Also human capital requirements in terms of knowledge for the correct application of CSA practices, and soil quality requirements for making CSA investment in agricultural intensification feasible are considered important. Finally, some CSA practices require application at scale (to guarantee externalities) and/or suppose good access to markets to enable the sales of additional output to compensate for initial investments.

A closer inspection of the importance of different resources and the conditions for the adoption of specific CSA practices provides insights into the critical barriers for implementation at scale. Even while most of the literature reviews tend to focus on initial capital investment requirement and access to credit as major constraints (for example for water management purposes, see Table 2), for some CSA practices such as intercropping, crop rotation and mixed systems, pest and disease management, key attention should be given to labor requirement and human capital constraints that enable farmers to further and continuous engagement with climate-smart farming. In addition, opportunities for the implementation of CSA practices may be highly locally-specific and are related to specific biophysical soil-weather supply conditions as well as favorable socio-economic and market demand conditions. It should be noted that these conditions may be competing, especially when population pressure requires more intensive land use (mono-cropping) and could lead to reduced crop (and diet) diversity. Finally, also economies of scope and scale can be important to enable sustained CSA adoption, particularly if initial sunk costs are high (such as for irrigation) or spatial externalities are critical (like for pest management).

A final criterion for the appraisal of the feasibility and likelihood of CSA adoption refers to the implications for farm-household welfare. This refers to the effects for improving farm income and household revenues and nutrition, the implications for engagement and employment of family labor, the opportunities for improving yields or stabilizing returns, and implications for risk and uncertainties as perceived by farmers.

It should be noted that the adoption potential of CSA practices also depends on the type of farmers, particularly considering differences in wealth (farm size), labor availability (family size and off-farm employment options) and available market linkages (distance and scale). CSA practices that require more fixed investments (i.e., irrigation; reforestation) are likely to be biased in favor of wealthier farmers, whereas smaller farm-households tend to prefer CSA practices that are more labor-intensive (e.g., mulching and intercropping).

The different CSA practices also register widely diverse outcomes in terms of net income, food security, employment and resilience. Investments for improved water and nutrient management can have substantial effects on yields and output (during various years), but also require substantial investments that can only be recovered if prices remain stable. While some CSA strategies focus on mixed systems and crop diversification, for improving bargaining power on markets a higher level of specialization and scale is required. Moreover, food and nutrition security is usually better guaranteed if farmers are also engaged in off-farm employment and non-farm activities. CSA practices that are more labor-intensive thus may result in reduced dietary diversity.

Such trade-offs between farm household welfare and sustainability objectives need to be considered to better understand CSA adoption decisions and outcomes. While resource endowments influence the (technical) possibilities for CSA adoption, ultimately behavioral preferences and risk perceptions finally determine the likelihood of CSA adoption. Effective policies look for tailoring incentives to behavior.

5. Supporting CSA adoption with precision policies

In order to identify suitable policy instruments that may support selective adoption of CSA practices, it may be useful to develop insights in the "*working sphere*" of different types of incentives for changes in investments and input application, land use and cropping pattern, and crop management practices. We therefore analyzed from the available literature the registered relationship of three major categories of policy incentives (see Table 3), namely (1) input and output prices (either from market exchange or influenced by taxes or subsidies), (2) changes in access to key resources (land and capital), and (3) changes in engagement with value chain and networks (through training or certification).

We use a heat map as a graphical representation of the importance of available evidence at each of the intersections between a policy incentive and a CSA practice, where the individual cells in the matrix are represented as colors (from green to red) that indicate the share of cases that provide evidence on the influence of incentives on the adoption of particular CSA practices. If more than 60% of the literature sources indicates that specific policy incentives have been relevant for adoption, this is shown by (light or dark) green cells. Similarly, if policy incentives only appear to be relevant in <40% of the studied cases, this is shown in by orange or red colors in Table 3.

Based on the information provided by the heat map, we can draw some conclusions regarding the frequency of reported impact for each of the policy instruments. This comprises research that mainly reports on the use of these policy instruments and—to a certain extent—also on the registered impact for farmers and the environment. Note that the heat map only provides insight on the evidence base, not on the intensity or the direction of impact.

Prices on input and output markets are most frequently reported as a strategy for enhancing fixed investments (farm infrastructures, irrigation and mechanization) and for supporting changes in cropping patterns, but are less relevant for adjusting input use decisions. Shifts toward agroforestry or hybrid seeds require not only higher prices and better margins, but also lower price volatility and greater certainty on future returns.

Subsidies are predominately used as a device for agricultural input support, mostly focussing on enhancing the adoption of mineral fertilizer (sometimes combined with drought tolerant), seeds and agro-chemicals to control pest and diseases. To a lesser extent bulky investments in irrigation techniques are supported with subsidized equipment, while public support by means of subsidies to stimulate the adoption of agroforestry and intercropping practices as well as crop rotation and mixed systems are relatively rare.

Land rights and tenure regulation are mostly reported as components for strategies toward land use intensification, particularly through common water management and to support (re)planting of perennial crops and the establishment of agroforestry systems. This requires usually a combination with rural finance facilities. To a lesser extent, land rights are relevant to enhance labor intensification of farming practices, either through nutrient management (cover crops; mulching) or within mixed farming systems. Far less impact is found of land ownership regulation on input use (seeds, chemicals).

The impact of rural finance instruments has been investigated mostly for soil and water conservation (SWC) measures. The effect of credit on the adoption of other types of practices is less documented: some evidence is available for the role of credit on water management and better adapted seed varieties, but credit effects on agroforestry, crop rotation and pest and disease management are hardly investigated. Some research on adoption effects of crop insurance is available, mostly related to intensification and resource efficiency, as well as SWC (Deryugina and Konar, 2017; Van Asseldonk et al., 2018).

There is scarce evidence about the effect of training and information on the adoption of CSA practices for water management, agroforestry and intercropping, as well as for crop rotation and mixed systems. Rigorous impact evaluation studies mostly investigate the impact of training and information on soil and nutrient management practices (e.g., organic and chemical fertilizer use), followed by analyses of their role in the adoption of practices for improving crop tolerance to stress and pest and disease management. Few studies, however, analyse the impact of the training and information on other categories of CSA practices (one study for each group).

Finally, certification and labeling exercise influence on the adoption of some Good Agricultural Practices (GAP) particularly for improving nutrient management and, to a minor extent, for pests and disease control. Since certification tends to enhance crop specialization, only minor effects are reported for changes in production systems. Due to rather limited long-term income effects, spillovers of certification toward fam investments also remain low.

Comparing the effectiveness of different incentive regimes for enhancing particular CSA practices, our overview indicates that price policies and factor market access programs are generally most important for CSA adoption, with the notable exception of agroforestry and mixed systems that are more knowledge- and labor-intensive for their implementation (and also generate revenues in the longer run). The working sphere of training and certification programs is fairly limited (most effects are found in the area of soil fertility management). However, programs of land titling and rural finance do benefit from combinations with farmer training and smallholder organization. Limited evidence is available on possible incentives to support better pest and disease management.

These findings provide clear evidence on the importance of understanding the linkages between the intrinsic opportunities and motives for the adoption of CSA practices and the effectiveness of extrinsic incentives. The likelihood of effective incentives for better soil and nutrient management is shown to be higher because it directly influences farmer's yields in the short run, as shown in field studies in Kenya (Kamau et al., 2014; Mutua-Mutuku et al., 2017), Malawi (Marenya et al., 2014) and Ghana (Bellwood-Howard and Al-Hassan, 2016). The same holds for investments in better seeds for reducing the incidence of crop diseases, that mitigate smallholders risks (Trujillo-Barrera et al., 2016) and contribute to more resilient household income.

On the other hand, agroforestry and crop rotation practices meet far more internal labor constraints and therefore external incentives are generally less effective for enhancing adoption. This is vividly illustrated by the high labor demands and the limited short-term revenues generated by agroforestry initiatives (Jacobi et al., 2017). Reducing capital constraints proved to be critical for adoption of drought-tolerant varieties (Holden and Fisher, 2015). Internal barriers are also found at the level of insecure land rights that limit farmer's engagement in in-depth investments for soil and water conservation measures (Lawin and Tamini, 2018). The same holds for knowledge-intensive CSA practices, such as integrated pest management (Godtland et al., 2004) and management of irrigation systems (Nakano et al., 2018). These internal constraints become even more important when gender-specific interests are considered (Howland et al., 2019).

6. Implications for policy and research

Reviewing the array of potential policy instruments as mechanisms for enhancing adoption and upscaling of potential CSA practices reveals that available empirical studies usually have a rather narrow focus on functional properties of a specific policy instrument and a particular CSA practice. They tend to ignore substitution, complementary or conditional effects between policy measures and CSA practices. An important aspect is to what extent these policy instruments are coherent with each other to simulate CSA adoption and what is the role and importance of these CSA instruments within the context of the whole package of public policies. The preferred set of policies should work positively together (i.e., complementarity) whereby the whole public policy package is more than the sum of its parts. In general, implementing policy options should be coherent while limiting potential distortions and externalities of public interventions. It is increasingly realized that mitigation and adaptation should not be pursued independently of each other but need to be considered as complements (Nyong et al., 2007). This also holds between the array of potential CSA efforts and other policy objectives and programs. For example, the promotion of new maize and wheat varieties is a more effective adaptation option when accompanied by policy interventions such as enabling credit access and fertilizer subsidy that mitigate potential capital and market access constraints (Holden and Fisher, 2015; Berger et al., 2017). Consequently, few incentives can be identified as particularly effective on their own, and thus there is no silver bullet that will solve the problems of vulnerable smallholders simply and instantly.

Our appraisal of the effectiveness and efficiency of incentives on CSA adoption only looks at inputs and outcomes and takes a generic approach with respect to the impact pathways that link inputs to outcomes. Wider perspectives on impact pathways point to the importance of sequencing and scaling for enhancing farmers' CSA adoption (Wigboldus et al., 2016). Feasible impact pathways are mediated by (individual and communal) factors that influence the likelihood of CSA adoption. Besides local conditions also attitude and perception of individual smallholders regarding the benefits and risks of technological change and innovation shape their behavioral responses (Yegbemey et al., 2013; Trujillo-Barrera et al., 2016). Similar incentives could lead to rather different outcomes, depending on the type of farm-household (i.e., with particular farm resource constraints and household characteristics) and the regional setting (functioning of markets and/or institutions). Contextual variables (such as the quality of infrastructure and governance structures) that support food system transitions at scale are of eminent importance. Consequently, we need to be cautions to draw straightforward conclusions with respect to the effectiveness and efficiency of (a set of) specific incentives, since this may depend on the interaction with intrinsic and extrinsic factors that shape the response reaction and adaptive capacity (De Souza et al., 1993; Deressa et al., 2009; Below et al., 2012).

The theoretical implications of this review point to the importance of identifying effective leverage points for enhancing CSA practice adoption from both the demand-side and the supply-side. Existing knowledge gaps concerning differences in adoption intensity of CSA practices can thus be addressed by linking suitable external policy incentives to internal behavioral drivers and material opportunities for adopting CSA practices. The feasibility of uptake of CSA practices increases when policies are used to align them with farm household resource endowments, livelihood strategies and market orientation. Better understanding of these interactions between extrinsic incentives and intrinsic drivers—mediated by differences in resource use requirements—influence the possibilities for smallholder adoption of CSA innovations and shape the opportunities for increasing their impact.

In summary, the array of potential policy instruments should jointly serve as a mechanism to enhance adoption and upscaling of potential CSA practices by small-scale farmers in low-income countries. Policies on market prices, taxes and subsidies, land rights, rural finance, training and information, and certification and labeling, may all drive smallholders decisions to invest in CSA practices. However, CSA adoption also requires that production and market risks, as well as producers' risk attitudes and perceptions should be addressed in the development "best-management practices" (BMPs)that complement knowledge on CSA practices (Asci et al., 2015). And that investment in these BMPs can cause reduced profits if the production and market conditions are not right. In addition, financing facilities and improved agricultural infrastructure are needed for particular CSA practices, such as water harvesting and climate-smart micro-irrigation (e.g., Wakeyo and Gardebroek, 2017). In summary, we advocate for more integrated approaches to CSA adoption that also consider indirect effects of policy instruments on smallholder welfare and that support their effective anchoring into policy packages that have proven to be successful for enhancing and sustaining widespread adoption of CSA practices.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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