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REVIEW

Are agricultural extension systems ready to scale up ecological intensification in East Africa? A literature review with particular attention to the Push-Pull Technology (PPT)

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Abstract
Agricultural extension, or advisory services, have a key role to play in supporting farmers' learning and adoption of new practices and technologies. This paper analyses gaps and needs which require addressing in order for extension systems to more effectively contribute to the upscaling of ecological intensification approaches in East African smallholder agriculture. Our starting point is the push-pull technology (PPT), a promising approach. PPT originated in East Africa and is being continuously improved through cycles of interdisciplinary and participatory experimentation. Despite well-documented benefits to farmers and the environment, more institutional support from agricultural extension systems (AES) is needed for PPT to realise significant impact on poverty reduction, food security, and sustainability. Departing from this assessment, we review literature on AES in five East African countries. After clarifying the AES characteristics that ecological intensification requires, emphasising the capacity to embrace complexity, we identify four thematic areas that are in urgent need of attention: first, widely recognised problems with access and inclusiveness have seen welcome innovation but remain substantial. Second, information and communication technologies provide many benefits and new possibilities, but expectations must be tempered. Third, pluralistic AES present coordination challenges that risk undermining and misdirecting extension. Finally, the political-economic underpinnings of extension require critical scrutiny and strategic interventions. While many challenges threaten extension effectiveness broadly, we highlight implications for ecological intensification approaches like PPT. Our insights thus speak to the broader question of how to design and implement extension for sustainable agricultural development in East Africa.

Keywords Advisory services · Technology adoption · Sustainable intensification · Pest management · Agro-ecology · Agricultural knowledge · Agricultural innovation

1 Introduction

Agricultural extension, also often referred to as 'agricultural advisory services', plays a crucial role in disseminating information and knowledge among researchers, farmers and other agri-food system actors, and in facilitating development, uptake and local adaptation of novel farming approaches (Benin et al., 2011; Birkhaeuser et al., 1991). However, agricultural development entails complex processes and agricultural extension systems (AES) are often facing challenges. AES have multiple roles to play, can be oriented towards different societal goals, and have undergone considerable changes over the past decades (Leeuwis, 2013). In the current era of (un)sustainable development, where problems such as climate change, biodiversity loss and soil degradation are becoming widely recognized and experienced in agriculture, AES have potential to contribute to more sustainable pathways of agricultural development, in addition to improved livelihoods and food security (Allahyari, 2009; Mapiye et al., 2021; Piñeiro et al., 2020). This is especially true as sustainable production systems tend to

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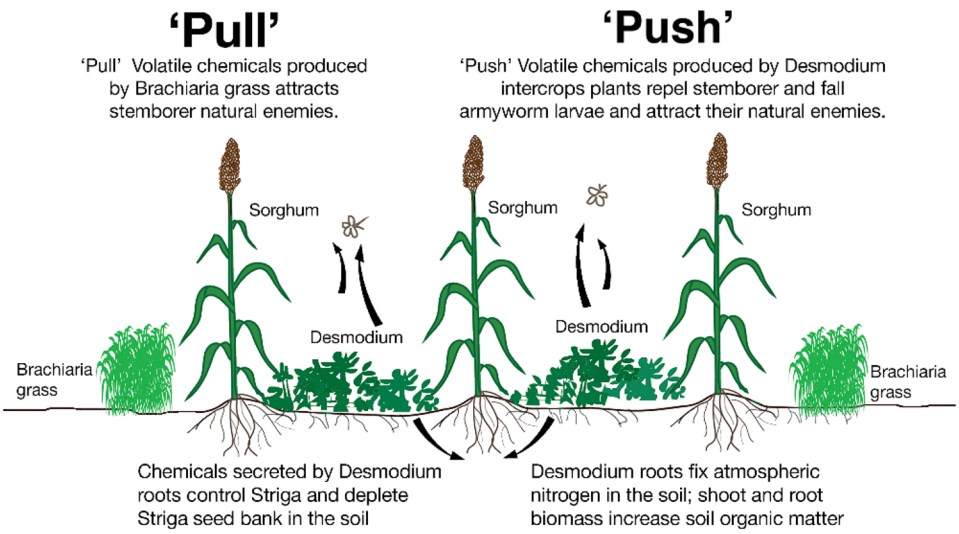

Fig. 1 Illustration of a climate-resilient push-pull technology (CR-PPT) field, here for producing sorghum, including the key mechanisms as currently understood. Image produced by *icipe*, reused with permission

be knowledge intensive (Altieri & Nicholls, 2012; Netting, 1993; Tilman et al., 2002).

A major challenge in sustainable agricultural development is that of pests, pathogens, and weeds, which in conventional agriculture is typically addressed through the use of agrochemicals. While pesticide use in sub-Saharan Africa (SSA) is still low by global standards, rapidly increasing use has been documented across the continent (Fuhrimann et al., 2022; Haggblade et al., 2022; Isgren & Andersson, 2021; Stein & Luna, 2021). This trend is fuelled by numerous factors, including new and/or increasing pest and disease problems (Prasanna et al., 2022), growing commercial agriculture (Rother et al., 2008), falling global prices of generic pesticides as their patent expire (Shattuck, 2021), and the intensified pesticide promotion by agribusiness (Vercillo et al., 2020). Human and environmental health risks associated with pesticide use (e.g. Jepson et al., 2020; Rani et al., 2021) are dramatically increased in contexts where regulation monitoring and enforcement, when existing, are poor. Beyond the necessary policies and enforced regulations required for pesticide usage in agriculture, the development and dissemination of farming systems and pest management approaches which minimize the need for pesticides is needed (Andersson & Isgren, 2021; Day et al., 2022; Nonga et al., 2011). These include for example Integrated Pest Management (IPM) and agroecological redesign (Kogan, 1998; Wezel et al., 2014).

The push-pull technology (PPT), wherein farmers grow companion crops to reduce pest damage while also suppressing harmful weeds, is a one such approach. PPT can be termed an agroecological innovation and a form of ecological intensification; production systems that are knowledge- rather than input-intensive and that have sustainable productivity through supporting ecosystem services (Bommarco et al., 2013). PPT was developed in the 1990s by the International Centre of Insect Physiology and Ecology (*icipe*), in collaboration with other Kenyan institutions, as a habitat management strategy for simultaneously controlling stemborer pests and *Striga* weeds in maize fields (Khan et al., 2000). Conventional or original PPT is now practiced by smallholders in parts of Kenya, Uganda and Tanzania, particularly in the high- and mid-potential areas and along the lake region, where cereals yields have been reported to double or even triple compared to controls (see for example Chepchirchir et al., 2017; Kassie et al., 2018; Khan et al., 2008a, b). PPT has been improved through farmer participatory research to address some of the limitations encountered, for example in regards to drought tolerance and disease problems, resulting in the development of a climate-resilient version of PPT (Fig. 1) in the mid-2000s. PPT research has above all focused on maize-based farming systems, but has also been extended to other staple crops such as sorghum, millet and rice (Pickett & Khan, 2016). In addition to helping farmers control major pests and weeds, PPT offers benefits such as the production of nutritious livestock feed (Desmodium, Bracharia and Napier grass), improved soil fertility and reduced erosion (Bhattacharyya, 2017). By enabling smallholder farmers to improve farm productivity without intensive use of external inputs, PPT has the potential to contribute to rural poverty reduction, improved food security and sustainable agricultural development in SSA (Fischler, 2010; Jain et al., 2023). This potential is enhanced by ongoing efforts to develop PPT for a wider range of agro-ecosystems, climatic conditions, and pests (Khan et al., 2014; Midega et al., 2018).

As PPT development progresses, new research questions emerge regarding how to best realise the benefits of the approach. In 2018 it was estimated that around 260,000 farmers practiced PPT, but given its demonstrated potential, more widespread adoption through effective dissemination

should be a policy goal for eastern African governments (Kassie et al., 2018; Khan et al., 2014). As noted, this puts agricultural extension systems in the spotlight. However, agricultural extension has historically often been criticised for ineffectiveness, especially in Africa (Dulle, 2000). Difficulties 'getting extension right' are linked to the fact that extension is always "embedded within the political economy of agrarian change" and thus shaped by powerful social and economic forces (Cook et al., 2021). Extension in SSA has its roots in colonial administrations' efforts to stimulate production of exportable commodities (Belay & Abebaw, 2004) which were often both coercive and exploitative in nature (Mukembo & Edwards, 2015). While colonial models of extension tended to outlive the presence of colonisers (De Vries, 1978), numerous shifts in AES have been seen in SSA in the past decades.– For example, the centralised, state-run "Training and Visit" models that dominated during the 1980s have shifted towards more decentralised, pluralistic models (Norton & Alwang, 2020). A discursive shift from 'extension' to 'advisory services' has also occurred (Davis, 2008) although the former term remains widely used. Despite the many reforms, small-scale farmers' access to effective and responsive extension services remains a concern in many SSA countries, and the crucial task of fostering sustainable agricultural development within the context of climate change and other environmental problems generates additional challenges in the present era (Amadu & McNamara, 2019; Nord et al., 2021).

This paper begins with a rapid review of PPT research, demonstrating its progress and potential as an ecological intensification method (e.g. Tittonell, 2014)[1] but also the need for greater attention to the role and functioning of AES for realising that potential. We then review academic literature on agricultural extension in East Africa, from the angle of the following question: which gaps and problems need addressing for extension systems to aid the upscaling of PPT and other ecological intensification methods more effectively? Our findings speak not only to the community of researchers and practitioners working on the PPT, but to the broader question of how to build extension systems that can effectively support sustainable agricultural development through ecological intensification in this region.

[1] We refer to PPT as a form of'ecological intensification'. While the term'sustainable intensification' is more widely used, its meaning has become vague as"almost any model or technology can be labeled under it" (Tittonell, 2014). Ecological intensification is more clearly defined as"the means to make intensive and smart use of the natural functionalities of the ecosystem (support, regulation) to produce food, fibre, energy and ecological services in a sustainable way" (ibid.). It reserves a major role for 'nature' or ecological processes in the design of multifunctional agroecosystems, thus we argue it is a suitable label for PPT.

2 Advances and gaps in the PPT research landscape: a rapid review

The development of PPT, also referred to as 'stimulodeterrent diversionary' strategies, was inspired by various intercropping methods long used by African subsistence farmers (Hassanali et al., 2008; Khan et al., 2014). Beginning with selection of potential trap and intercrop plants in 1995, followed by the first experimental trials in 1996, the researchers sought to better understand how companion crops might be utilised to control pests that were causing significant damage to the region's staple crops (Khan et al., 2000). A particular focus was the lepidopterous stem borers that attack cereal crops. Through basic research and farmer-participatory field experiments, originally mainly on maize, researchers identified specific cattle forage grasses (Napier and Sudan grass) as promising attractants for stem borers (pull), while the forage legume *Desmodium* seemed to function well as a repelling intercrop (push). The original version of the technology thus involves intercropping of a fodder legume *Desmodium* spp., including *D. uncinatum* (Jacq.), with cereals and a perimeter of Napier grass, *Pennisetum purpureum K.* (Schumach), planted around the plot (Khan et al., 2000, 2016). Aside from reducing stem borer damage, PPT was also found to help farmers suppress a difficult weed, the parasitic *Striga* or African witchweed (Hassanali et al., 2008) and improve soil fertility by fixing nitrogen, improving soil biomass, controlling erosion and acting as a natural mulch (Khan et al., 2016).

The operational mechanisms of PPT have been extensively described elsewhere (see Cook et al., 2007; Khan et al., 2002, 2010; Midega et al., 2015; Pickett & Khan, 2016) although its mechanisms are complex and some remain debated (David, 2022). PPT has consistently involved farmer participatory research to address some of the limitations encountered. For example, its expansion in drier areas was limited by inability of silverleaf desmodium to withstand long period of dry spells, and the Napier grass suffered from the stunt disease reducing its effectiveness (Khan et al., 2014; Midega et al., 2015). This led to the development of a climate-resilient push-pull technology, CR-PPT, in the mid-2000s. This involved intercropping cereals with drought-tolerant C, *Desmodium intortum* (Mill.) Urb., and planting *Brachiaria* cv Mulato II as a surrounding border crop (Khan et al., 2014; Midega et al., 2015, 2017). The CR-PPT was also adapted to incorporate other brachiaria cultivars (such as Basilisk, Xaraés and Piatã) that were more tolerant to red spider mites (Cheruiyot et al., 2018a, b, c). Most recently, a 'third generation' of push-pull technology (3G-PPT) was developed, which uses the new companion crops *D. incanum* (push) and Xaraés (pull) to provide even greater resilience to hot and dry conditions (Cheruiyot et al., 2021). It has also been shown

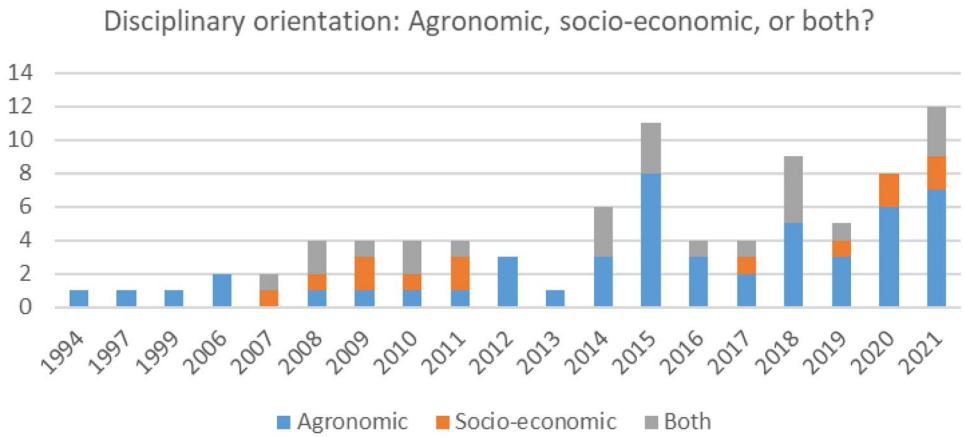

Fig. 2 Overview of the disciplinary orientation of PPT research over time, showing that this research efforthas long been multi- and interdisciplinary

to be possible to integrate vegetables and legumes into PPT systems, further enhancing the appeal in terms of food security (Chidawanyika et al., 2023; Fischler, 2010).

While much of the research on PPT has been agronomic in orientation, it has consistently also included socio-economic aspects (Fig. 2).[2] It quickly became apparent that farmers' perceptions needed to be studied, to understand how the attributes of this technology may influence its adoption (Khan et al., 2008a, b). Also the economics of PPT, in comparison to other practices, had to be assessed (Khan et al., 2008a, b). PPT development thus reflects the growing emphasis on multi- and interdisciplinary approaches generally seen in agricultural research (Isgren et al., 2020). In addition to the research carried out in laboratory and experimental field settings, farmer participatory approaches have been employed to evaluate and improve the technology's performance and outcomes. This has included the assessment of factors that encourage or hinder adoption amongst different groups, and allowed for attention to the heterogeneity of smallholder farmers (e.g. in terms of agroecological conditions, resources, decision making power) and interactions between farming system components (Cockburn et al., 2014; Khan et al., 2016; Murage et al., 2015). For example, researchers have found that factors such as a farmers' age, gender, education, access to extension, farmer group membership, and perceived benefits shape adoption (Maina et al., 2020; Murage et al., 2015; Muriithi et al., 2018; Niassy et al., 2020). Numbers and types of animals kept by farmers also matter, since the companion crops typically utilised in PPT are fodder crops (Maina et al., 2020). The adoption of PPT is furthermore interrelated with other practices, due to various complementarities and trade-offs (Muriithi et al., 2018).

The interdisciplinary and participatory nature of PPT research has thus yielded rich insights. There is still need for further research to understand the exact mechanisms at play in PPT systems, and how to overcome management and performance challenges from a farmer perspective (David, 2022). But we also noted another important gap. The fact that PPT has the agronomic potential to be upscaled across a wide range of agroecosystems in the region accentuates the question of the social context and its variation. Farming systems are themselves diverse and complex, but they are also situated in a broader social (political, economic, cultural) landscape which shapes their performance and development (Isgren et al., 2020). As noted, some socio-economic questions – such as impacts of PPT on farm economy or differences in adoption between groups – have received attention. However, the analyses have mainly focused on the level of the individual farm, farmer or household, and much less so on the societal level (Fig. 3). By this, we mean actors, processes and structures outside of the individual farm or household, such as social institutions.

This limits our understanding of how broader social forces shape the development, dissemination and uptake of PPT. There are clear indications that such understanding is important – and that agricultural extension should be a key focus. Bàrberi (2019) points out weak agricultural extension as an institutional obstacle to wider uptake of ecological weed management in SSA and Day et al. (2022) note the same for Integrated Pest Management (IPM), both of which PPT can constitute part of. Specifically for PPT, Kassie et al. (2018) highlight the role of extension when noting that "it is crucial not only to adapt the PPT system to existing farming practices […] but also to engage the private and public sectors to actively promote PPT adoption". Providing support for farmers to learn and adapt

[2] Our rapid review of the PPT literature (last updated in early 2022) was conducted using the Web of Science database. 86 abstracts were analyzed to ascertain disciplinary orientation, research focus and level of analysis.

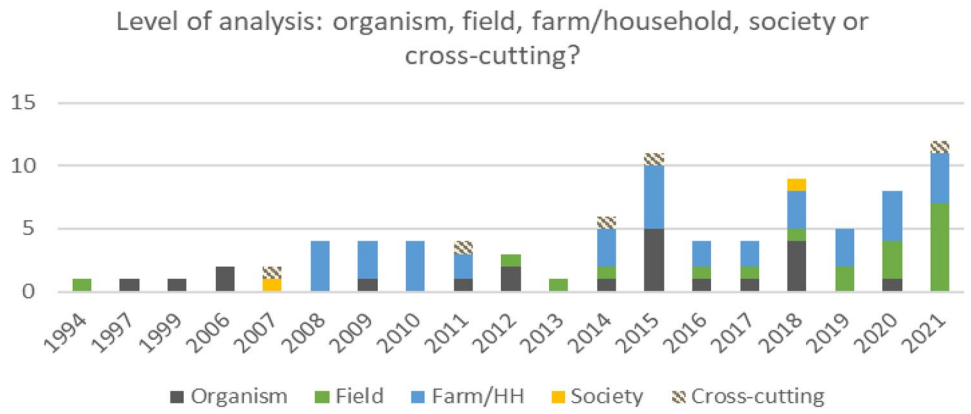

Fig. 3 The level of analysis in PPT research has commonly ranged between the organism (a specific crop and/or pest) to the field and the farm/household. Meanwhile, studies seriously engaging with the societal level (e.g. social institutions beyond the farm/household) are few. This limits our understanding of how the broader social landscape influences PPT adoption and performance

PPT is particularly important because, like other agroecological methods, it is a knowledge-intensive technology. The documented success stories of PPT dissemination, achieved through the efforts of specific institutions and partnerships, reveal the importance of deploying "a combination of dissemination pathways catering to different socio-cultural and socio-economic contexts of farmers" (Khan et al., 2014). Certain extension approaches are particularly effective, such as field days, farmer field schools and training of 'farmer teachers' (Murage et al., 2012). Farmer-to-farmer networks seem to be key as these produce a considerable "multiplier effect" (Amudavi et al., 2009a, b). Still, contact with professional extension – ideally on a relatively frequent basis – is crucial (Khan et al., 2008a, b). Thus, insufficient support from national extension systems forms a bottleneck for wider and more sustained adoption (Khan et al., 2014). Against this background, the remainder of this paper analyses scholarly literature on AES in East Africa, to identify key challenges and questions with regards to AES support of ecological intensification – discerning specific implications for PPT, when possible.

3 Methods

We arrived at our findings through conducting a query-based review of peer-reviewed scientific literature, analysed through qualitative coding. Since we sought to develop insights on a relatively broad research question which required inferences regarding implications for ecological intensification and PPT, we opted for a narrative review rather than a systematic review. This enabled a more exploratory and inductive approach; however to improve rigour and transparency we also borrowed aspects of systematic review (Ferrari, 2015) including well-defined search terms and clarity regarding inclusion/exclusion. The original search was done in January 2021 using the following Web of Science (WoS) database query: "agricultural advisory*" OR "agricultural extension" OR "rural advisory*" OR "rural extension" OR "extension service*", refined by: Uganda OR Kenya OR Tanzania OR Ethiopia OR Rwanda OR "East Africa".[3] A rapid review of titles and abstracts reduced the initial 569 articles to 430. Through a subsequent, more in-depth, review this was reduced to 163 articles, deemed to contain empirical insights regarding the characteristics and/or functioning of AES in the focal region (for example, many articles solely stated the importance of extension for promoting certain practices, and were excluded). We included articles containing general discussions about extension in East Africa or SSA, but not articles focusing specifically on countries outside our geographic delimitation. In January 2022, the search was updated to include publications from 2021. In addition, we applied the same query to the Scopus database, having noted the absence of some highly relevant journals from WoS. After removing duplicates and performing the same screening procedure, we finally analysed a total of 237 publications in full (both databases combined).

An initial analysis was done to understand the temporal and geographic distribution of the literature (Fig. 4). We found Ethiopia to be the most commonly studied country (76 articles) and Rwanda the least (10). The earliest publication in the sample was from 1978 but the vast majority (> 90%) of publications were from 2008 and after. In-depth content analysis involved summarising key findings from each article, and then coding these thematically through multiple cycles. While there is always a degree of subjectivity in this process, the coding process aimed at transparently developing a workable set of themes (Skjott Linneberg & Korsgaard, 2019). A list of initial codes and

[3] 'East Africa' is a larger region (depending on the definition), but this delimitation was made on practical grounds, as the study was conducted as part of the ongoing Horizon2020 project"UPSCALE" which studies PPT in these five East African countries.

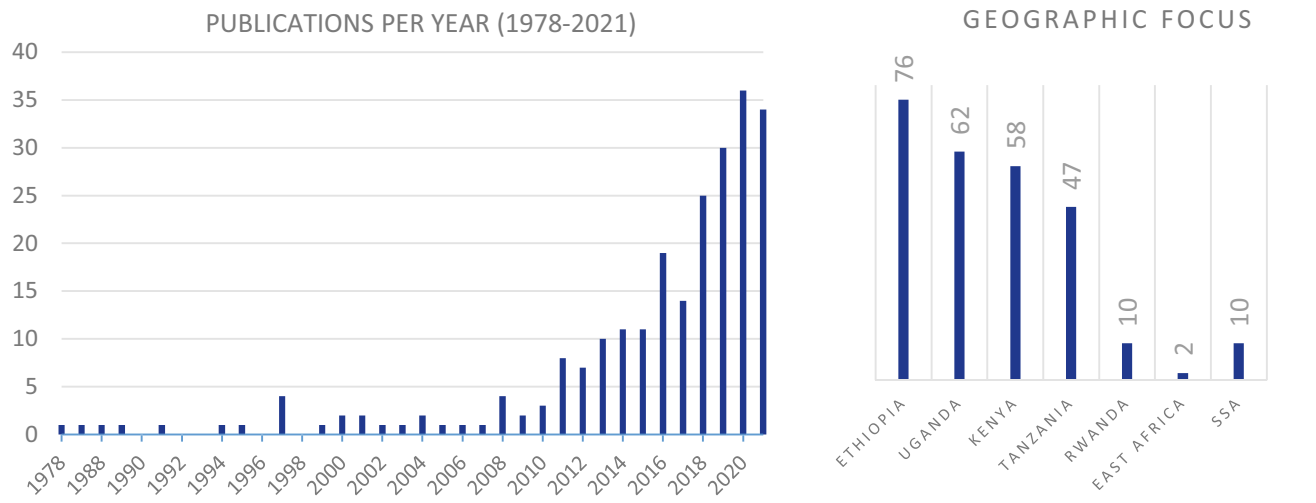

Fig. 4 Left: Distribution of reviewed publications over time (publication year) since the earliest included article in our sample (1978) through 2021. Right: Geographic focus of the reviewed publications. Note that some publications focused on multiple countries/regions, hence together they amount to > 237. Agricultural extension has received the most scholarly attention in Ethiopia, although the distribution is largely proportional to country population size

resulting themes can be found under Supplementary information (Table 1). In the first round of coding, each article was given one or several brief descriptive codes to reflect its contribution to our understanding of agricultural extension, e.g. 'gender' or 'climate change'. In the second round this process was repeated to improve and harmonise the codes (combining nearly identical ones, adjusting to more precisely reflect the content, adding codes for overlooked content). In the third round, we grouped codes into broader themes, e.g. 'access and inclusivity' or 'extension for sustainable agriculture'. Finally, we went over the article summaries again to identify any initial codes that were not well-captured in the themes. These were either grouped with an existing theme (adjusting the theme, if necessary) or else we determined that the associated findings were better treated as cross-cutting and incorporated where most relevant (for example, this was done for the codes 'evaluation of a specific approach/model' and 'impacts of extension'). To avoid taking findings out of context and to enhance the validity and relevance of our findings, we also intermittently returned to the articles throughout the coding and writing processes, as suggested by Skjott Linnberg and Korsgaard (2019).

The analysis process ultimately produced five themes, presented in the following. Throughout, we elucidate how the findings relate to ecological intensification and the question of PPT upscaling. We largely seek to produce insights of general significance for the region, as previous research has indicated that similar extension challenges exist across East Africa (Msuya et al., 2017). When deemed important, we also highlight country-level differences and particularities.

4 Analysis

Our analysis is presented as five themes. First, we detail why and how sustainable agricultural development through ecological intensification[4] in smallholder contexts create specific needs and challenges for AES in the study region (Sect. 4.1). We then cover three areas that the literature points out as of general importance for improving effectiveness of extension, while highlighting implications for ecological intensification approaches: addressing persistent problems regarding access and inclusivity (Sect. 4.2); harnessing the power of information and communication technologies (ICTs) (Sect. 4.3); and coordinating pluralistic AES (Sect. 4.4). Finally, we present findings which reveal deeper drivers of the extension challenges identified, more specifically the political economy of rural development and the 'politicisation' of extension (Sect. 4.5).

[4] N.B. that the analysed literature spoke varyingly of ecological intensification, sustainable intensification, conservation agriculture, agroecology, sustainable agricultural practices, integrated pest management, etc. An important part of our analysis was to assess the relevance of the findings and translate them into implications for ecological intensification and (when relevant) PPT.

4.1 Extension for ecological intensification: embracing complexity

We identified a number of concerns regarding the capacity of AES to provide effective extension services and technical assistance to support the development of diverse, resource conserving and adaptive farming systems (Piñeiro et al., 2020) along the lines of ecological intensification. More specifically, extension services must be capable of supporting farmers through cycles of knowledge uptake, application and evaluation in a manner that is sensitive to social, economic and agro-ecological heterogeneity, and changing environmental conditions (Haug, 2016; Khan et al., 2014). Farmers need capacity to diagnose problems, respond with context-appropriate actions, and engage in lifelong experimentation and iterative learning, something that current extension services often struggle to support due to limited resources for extensive field visits and demonstrations (Ortiz-Crespo et al., 2020). This particularly hampers ecological intensification, which requires in-depth knowledge about local socio-ecological systems as well as of landscape dynamics (e.g. Geertsema et al., 2016).

Inevitably, upscaling complex agricultural practices demand forms of extension that are relatively costly, such as farmer field schools (Day et al., 2022). To support sustained adoption it is crucial to utilise participatory approaches that allow contextualisation and facilitate social learning or "learning among people through social observation" (Bourne et al., 2021). Farmer-participatory approaches are key to enable identification of practices and technologies that make sense given particular biophysical and socio-economic conditions (Ainembabazi et al., 2017), and to foster farmers' capacity for autonomous experimentation (de Jager et al., 2004). Recent decades have seen welcome policy shifts towards more participatory extension approaches in most of Africa, including East Africa. Yet this has not always translated into practice (Brown et al., 2018b; Friis-Hansen & Duveskog, 2012; Kiara, 2011) and a 'transfer of technology' perspective remains prevalent (Brown et al., 2018a). In Uganda for example, the National Agriculture Advisory Services (NAADS) programme aimed for a demand-driven, farmer-centric approach but many agents continued to provide information "as they would under a Training and visit (T&V) model" (Pincus et al., 2018). Regassa et al. (2019) identify serious challenges also in Ethiopia, as local development agents often lack the expertise needed to provide meaningful site-specific advice. Despite the rhetoric of participation in Ethiopian extension, "the provision of fertilizers, improved seeds, credit, and agricultural training […] is given in a top-down approach by considering farmers as "passive receivers"" (Tsige et al., 2020), while smallholders' real needs remain largely unmet (Leta et al., 2020a, b). In contrast, Leta et al. (2020a, b) suggest that the novel approach to piloting and demonstrating new technologies used within the donor-funded Integrated Soil Fertility Management Project ($ISFM^+$) could function as a model to be integrated into Ethiopia's mainstream extension system, given its high performance in terms of farmer participation and local adaptation.

Rather than treating farmers as passive recipients, effective promotion of ecological intensification and sustainable practices more broadly requires that extension agents respect, engage with, and build on farmers' existing knowledge, practices, and aspirations (Dilley et al., 2021; Nord et al., 2021; Pincus et al., 2018). Joint experimentation is crucial; otherwise, farmers may feel that a new practice is an 'experiment' managed by outsiders, as observed in Fischler's (2010) assessment of PPT. Chikozho (2005) found evidence that the farmer-extension agent relationship in Tanzania is transitioning towards a more interactive and "mutually symbiotic" state, which importantly enables extension agents to learn from farmers and feed farmers' knowledge into research. Still, extension agents sometimes have predefined agendas that cause them to neglect indigenous technologies and practices such as intercropping (Nord et al., 2021) and urge or even coerce farmers to replace them with 'modern' technology packages (Eneyew, 2021). On the other hand, farmers may also lack important knowledge or hold misconceptions that clash with promising new concepts and practices. In a study from Ethiopia, Nyang'au et al. (2018) describe how PPT clashed with the entrenched practices of maize monocropping and freely grazing livestock, something extension agents had limited experience dealing with. Such situations call for "convincing and concerted efforts" by extension agents who are well-versed in the local setting and can lead hands-on experimentation, coupling 'how-to' knowledge with 'principles' knowledge – that is, showing how and *why* a practice works (Pincus et al., 2018). This is pertinent to PPT, albeit challenging, as the complex mechanisms at work in the technology may not be fully understood yet (David, 2022).

Waithaka et al. (2006) and Pan et al. (2018) highlight how an important role of extension is creating awareness amongst farmers of how farm management changes can substantially impact revenues and food security. Unsurprisingly, adoption is facilitated by clear benefits and limited trade-offs (Verkaart et al., 2019) and farmers are sometimes deterred from adopting sustainable practices by "lagged impacts or limited tangible short-term outcomes" (Wafula et al., 2016). This particularly disincentivises adoption amongst those who struggle to meet short-term household needs and/or have insecure land tenure. In the case of PPT, some benefits may manifest themselves quickly, while others (such as improved soil health) may take longer (David, 2022). Being a 'multifunctional' practice, the impacts are numerous and farmers may value them differently (Abresparr, 2015). Costs

and labour requirements are both important aspects to consider. Ecological intensification tends to be relatively low-cost by reducing the need for external inputs, and PPT has also been found to be labour-saving for smallholder households by reducing the need for weeding and ploughing (Diiro et al., 2021). This is not universal for ecological intensification methods, however, and PPT even requires higher labour inputs at certain times, not least initially (Fischler, 2010). Where impacts are complex and sometimes lagged, Wafula et al. (2016) recommend coupling theoretical trainings with demonstrations and frequent follow-ups, using community facilitators as focal persons, and electing farmer volunteers to strengthen the adoption process in a cost-effective manner. This aligns with PPT research that has found field days, farmer field schools, and 'farmer teachers' to be promising dissemination tools (Amudavi et al., 2009a, b). However 'one size' does not fit all and the exact approach should be tailored to the constraints and preferences of the target group in mind (Murage et al., 2011).

Challenges to fostering ecological intensification methods can importantly be linked to how 'success' in extension work is measured. Regarding Ethiopia's PADETES programme, Spielman et al. (2010) for example note that "the success of the extension services has been traditionally measured in terms of targets for physical input use" and that "most extension agents view their role primarily as distributing fertilizer and credit", which undermines technical advice provision. In the area of pest management, a related issue is that 'safe use' of pesticides is promoted by industry actors as the main way to make pest management sustainable. While important, the safe use discourse risks entrenching approaches centred on external inputs, while undermining investment in dissemination of alternative pest management approaches (Isgren & Andersson, 2021).

Finally, although we did not find any published evidence on extension agents' knowledge of, or attitudes towards PPT, specific knowledge gaps likely exist. Schut et al. (2015) found Tanzanian extension agents to show 'low awareness' of parasitic weed problems – an important motivator for PPT adoption among farmers (D'Annolfo et al., 2021). Also knowledge gaps amongst extension agents regarding biological control agents have been identified as a barrier to sustainable pest management (Dougoud et al., 2018).

4.2 Access, inclusivity and continuity – persistent challenges and potential solutions

Smallholders' access to agricultural extension in East Africa remains highly uneven and a major barrier to uptake of new technology and practices (Brown et al., 2018a; Kingiri, 2020; Leta et al., 2018a, b; Nyairo et al., 2021; Piemontese et al., 2021). Several authors point to Structural Adjustment Programs and associated cut-backs in public spending in the agricultural sector as an important cause, while noting Ethiopia as the exception (Berhanu & Poulton, 2014; Dercon et al., 2009). But here also, systematic inequalities in access to extension remain a problem (Leta et al., 2018a, b) especially in remote areas where extension workers tend to be fewer, younger, and less experienced (Abate et al., 2020). Knowledge intensive practices require not only exposure to new knowledge but also continuous interaction with advisors – for PPT, over several cropping seasons (Nyang'au et al., 2018) – which many farmers lack (Murindangabo et al., 2021). The literature frequently documents inequalities along economic and geographic lines (AfranaaKwapong & Nkonya, 2015; Jensen et al., 2019; Kingiri, 2020; Lameck & Hulst, 2020). Lameck and Hulst (2020: 759) for example conclude from a Tanzanian study that:

> "Confronted with scarce resources and a difficult physical environment, they [extension agents] choose the easy way out: to visit nearby farmers' groups; provide services to groups for which financial resources have been made available; and, most of all, service paying farmers"

To safeguard inclusivity, attention is therefore needed to the ways that extension agents get financially compensated. The trend of privatisation and 'cost-sharing' risks further marginalising the poorest (Wordofa, 2019), and innovative regulation in the form of extension price-caps and subsidy systems to achieve more even coverage might be needed (Blum, 2020).

Gender inequalities in access to extension services are similarly widespread and persistent (Abdu-Raheem & Worth, 2017; Badstue et al., 2020; Gebrehiwot, 2017; Hampson et al., 2017; Kansiime et al., 2021; Kingiri, 2020; Mogues et al., 2019; O'Brien et al., 2016; Ragasa et al., 2013). Farnworth et al. (2016) also describe a persistent conceptual 'lock-in', wherein services remain tailored to the norm of the 'male farmer'. These issues are well-known (e.g. Muzaale & Leonard, 1985) and a common response to reach female farmers more effectively has been to recruit more female extension agents, which can be impactful (Achandi et al., 2018; Buehren et al., 2019; Mogues et al., 2019). However, women farmers may still face gendered constraints to adoption, related to for example land ownership, household decision-making, education, representation in local organisations, and access to communication technology. Such constraints can directly or indirectly affect the ability to access and utilise extension services. Beyond employing more female staff, this calls for explicit targeting of female farmers, capacity for gender analysis, and approaches that foster intra-household cooperation and women's empowerment (Ariong et al., 2016; Percy, 1999). That said, it is also important not to simplify the role of gender in agriculture through overly generalised and possibly outdated assumptions e.g. around "women's crops/men's crops" (Williams & Taron, 2020).

Social learning and farmer-to-farmer approaches have been proposed as effective means of knowledge transfer, with potential to mitigate access and continuity problems (Abi et al., 2019; Dowsing & Cardey, 2020; Hailemichael & Haug, 2020; Leta et al., 2018a, b). For example, in a Kenyan study, Kiptot and Franzel (2019) demonstrate the potential of 'volunteer farmer-trainers' who receive continuous training from extension staff and then work closely with producer organisations and farmer groups. A Tanzanian study on 'village-based advisors' present similarly promising findings (Kansiime et al., 2018). Given the importance of social learning, Ngango and Hong (2021) argue that farmers' cooperatives should be given "priority as a dissemination pathway", which is also supported by Abebaw and Haile (2013). Ainembabazi et al. (2017) emphasise the role of farmer group membership, especially when combined with access to government extension services, in accelerating technology uptake. Dowsing and Cardey (2020) suggest that working with (or even establishing) organisations at the community level helps scaling AES efforts and facilitates local tailoring of services. Aside from the fact that learning from fellow farmers can produce more lasting effects (Krishnan & Patnam, 2014), several studies have identified additional benefits associated with group-based extension approaches in terms of empowerment and social capital (Friis-Hansen & Duveskog, 2012; Kiptot & Franzel, 2019; van Rijn et al., 2015). That said, many farmers actually prefer individualised extension over group approaches, so striking a balance between the two is important (Kingiri, 2020). The level of local adaptation and system redesign that practices, such as PPT would require, underscore the continued need for individualised extension, alongside collective activities such as field days (Murage et al., 2012).

To realise the desired outcomes of farmer-to-farmer extension, its core principles, of reciprocity, collaboration and minimal hierarchies, must be reflected in practice. Yet, this is not always the case (e.g. Hailemichael & Haug, 2020). Dissemination via social networks can be plagued by issues of exclusivity and mistrust, especially when 'lead farmers' are provided with material support such as inputs (Brown et al., 2018b). A good understanding of which local social networks (and individuals within) that are suitable to target is therefore required, in order to amplify extension efforts (Mekonnen et al., 2018; Van den Broeck & Dercon, 2011). Not only is it important to know who the members or participants are, and which categories of farmers are represented, but also how networks are internally organised and coordinated, and their links to other stakeholders (Gramzow et al., 2018). The common practice of focusing on so-called 'lead' or 'model' farmers is not always effective for disseminating information, because those farmers may neither be typical (e.g., socio-economically) nor the most connected to fellow farmers (de Roo et al., 2021). Socially connected farmers may be important opinion leaders, but are not necessarily the most receptive to extension, or in need of it (Matouš et al., 2013). The issue of continuity remains also important when seeking to amplify extension through locally-based 'farmer-advisors'. For such efforts to be sustained, investing in suitable incentive structures (financial and others) is crucial to sustain motivation among farmer-advisors (Kansiime et al., 2018; Kiptot & Franzel, 2014; Kiptot et al., 2016).

Furthermore, scholars have long been cautioning that farmer-to-farmer learning can amplify but not *replace* professional extension. There is a need for greater public investment in formal extension. This encompasses not only recruitment of new staff but also continuous training, provision of quality materials, and proper working conditions that help retain and motivate extension staff and enable continuous interaction with farmers (Abate et al., 2020; Marinus et al., 2021; Matouš et al., 2013; Mtega & Ngoepe, 2019; Ortiz-Crespo et al., 2020; Raile et al., 2021; Regassa et al., 2020; Schut et al., 2015). However, as shown by a recent report by the FAO (Pernechele et al., 2021), African countries are spending less per capita on agriculture relative to other regions in the world. The majority of counties fail to meet the 10 percent target set by the Maputo declaration, despite renewed commitment in 2014. Furthermore, while spending on public goods such as research and knowledge dissemination (including extension, technical assistance and training) is recognized to have the largest effects on agricultural growth and poverty reduction (compared to, for instance, input subsidies), such expenditures are comparatively low and even decreasing for the SSA region overall.

4.3 Harnessing the power of ICTs – and avoiding pitfalls

There is considerable interest in the use of ICTs within the scholarly literature on extension in East Africa, as well as amongst policy makers and donors (McCampbell et al., 2021). In particular, the potential of mobile phone-based technology – from simple messaging services to more advanced applications – has generated much research activity, motivated by the rapidly growing use of mobile phones in rural areas (Mapiye et al., 2021). A major benefit is that phones can facilitate communication between extension agents and farmers, who tend to live remotely and dispersed. This can enable farmers to access advice in a time-efficient and flexible manner (Dione et al., 2021) and potentially increase extension reach while reducing costs and workloads (Cotter et al., 2020; Ochilo et al., 2019; Ortiz-Crespo et al., 2020; Van Campenhout et al., 2021). Many different types of relevant information can be relayed via phone – such as market prices, weather forecasts, and agronomic knowledge (Van Campenhout et al., 2017). Smartphone applications can also facilitate supervision and performance tracking of staff (Amadu & McNamara, 2019; Namyenya et al., 2021), and

serve as tools for information gathering, diagnostics, data collection and communication amongst extension workers (Mrisho et al., 2020; Wright et al., 2016).

In addition to facilitating long-distance communication, ICTs can transmit other kinds of information than face-to-face communication. For example, visual tools such as video can be effective in disseminating knowledge (Van Campenhout et al., 2017, 2021). This can be useful for example when demonstrating new farming systems and practices, as real-world demonstration sites take time and resources to establish and may be inaccessible. Radio, which has long been used to get messages out to farmers, can also be an effective communication channel even around quite complex subjects. With regards to climate change adaptation, for example, Mwaniki et al. (2017) highlights the use of social learning approaches such as 'listening clubs' as an important area for further exploration, as these may amplify the impact of ICTs. The potential of ICTs to spur discussion amongst farmers is also emphasised by Hampson et al. (2017) regarding radio, and by Clarkson et al. (2018) regarding agriculture-themed television 'edutainment'. The growing use of mobile phones further provides opportunities to make older ICTs (such as radio) more interactive, which also can enhance their impact (Hampson et al., 2017). That said, Nord et al. (2021) caution that many projects that champion ICT-based extension are actually perpetuating outdated modes of linear technology transfer.

An area of particular interest to PPT is the use of ICT to assist farmers in managing pests. For example, mobile phones, tablets and specially developed applications that enable data recording and communication can greatly enhance the work of 'plant clinics', which offer direct assistance to farmers on crop pest diagnosis and control strategies (Ochilo et al., 2019). Ortiz-Crespo et al. (2020) found similarly positive impact of an automated hotline developed in Tanzania through a participatory process known as 'user-centred design'. A study of ICT-based extension campaigns to help Ugandan farmers respond to a novel pest outbreak (fall armyworm) found that a combination of interactive radio, Short Message Services (SMS) and video screenings significantly increased farmers' knowledge about the pest and stimulated the adoption of pest management practices (Tambo et al., 2019).The authors particularly emphasise the complementarity of the different technologies, as they allow for different kinds of communication and have their own strengths and weaknesses (e.g. reach, impact). Van Campenhout et al. (2021) meanwhile found little evidence of complementarity between video, interactive voice response and SMS reminders in extension around maize management, suggesting that the outcomes depend on the specific technologies and/or the issue at hand.

Accessibility of ICTs, however, remains an important concern. With increased use of ICT-based extension, are there risks of leaving out certain groups? Many small-scale farmers in the region still lack access to smart phones and internet, and even to basic mobiles and radio (Getahun, 2020; McCampbell et al., 2021; Raile et al., 2021). It is crucial to base interventions on a solid understanding of the availability and usage of different communication channels (Mtega, 2021). Tata and McNamara (2018) especially emphasise gender differences, for example regarding financial resources and norms around technology use. Kingiri (2020) notes that ICTs are meant to (and can) improve inclusivity, yet in fact often exclude resource poor farmers and women. Ochilo et al. (2019) concur, but also found evidence that initial barriers to technology use can be overcome if the right support is provided. There are also studies which found no significant difference between men's and women's participation, for example Tambo et al. (2019) on ICT-enabled extension for fall armyworm management in Uganda. Another caution is that ICTs can complement but not replace 'traditional' extension (Mwaniki et al., 2017). For example, Karubanga et al. (2016) found video-mediated extension to be better at awareness creation and sharing of knowledge and experiences, while face-to-face methods excelled at enhancing knowledge acquisition, retention and application. Nor do ICTs circumvent the need to be cognizant of heterogeneity and complexity. For example, for video-messages to work they need to be clear, concise and applicable to a heterogeneous audience, which in turn may call for customisation (Van Campenhout et al., 2017). Finally, it is not only the accessibility, acceptability and skills at the farmer level that require attention. Barriers in terms of access, experience and attitudes can also exist amongst extension staff (Birke et al., 2019). Importantly, meaningful integration of ICTs require "appropriate institutional arrangements and technical capabilities" in the AES (Karubanga et al., 2016:11).

4.4 Coordinating and designing pluralistic extension systems

As extension has moved towards pluralistic, decentralised and partly privatised systems (Abdu-Raheem & Worth, 2017; e.g. Birner et al., 2009), new challenges related to coordination and accountability have emerged (Malima et al., 2020; Mukembo & Edwards, 2015). This is a general concern for AES, but even more so for supporting ecological intensification, as coordinated action at the landscape level is crucial (Geertsema et al., 2016). First of all, even within the public sphere there may be multiple agencies and ministries involved. This can result in unclear roles and responsibilities, conflicting ideologies and competition over resources, as for example seen in Uganda (Danielsen et al., 2014; Joughin & Kjær, 2010; Rwamigisa et al., 2018). Placing responsibility for extension on local governments

can bring decision-making closer to farmers, but can also lead to decline of services if not accompanied by adequate resources, role-setting, and institutional capacity building (Anderson & Crowder, 2000; Benin et al., 2011; Danielsen & Matsiko, 2016).

Second, as actors from the private sector and civil society become involved in extension, inadequate coordination can cause inefficient resource use, contradictory approaches, and exclusion. Farmers' trust in extension institutions and confidence in the skills of extension agents are important success factors for AES, especially when it comes to complex, knowledge intensive practices (Kassie et al., 2015, 2020). This can be challenging to achieve in a complex and changeable extension landscape. Mwololo et al. (2019) caution that under privatisation, the state needs to stay active in guiding investment and activities, and servicing farmers who cannot afford private extension. Yet, low public funding of both extension and the agricultural sector overall long has been a concern in East Africa, and remains so (Pernechele et al., 2021). Mtega and Ngoepe (2019) further note that "to enhance access to agricultural knowledge, all actors involved in creation, sharing and usage of knowledge must interact continuously". This has proven to be a widespread challenge. In Uganda, Bruce and Costa (2019) identify a lack of "appropriate policy that supported and guided private sector emergence and involvement in the extension programme [NAADS]". This contributed to the gradual diversion of the programme's mandate, including a shift back towards a supply-driven approach centered on input-provision. There have also been reports of nepotism in the process of contracting private service providers. In Kenya, Kiara (2011) notes insufficient harmonisation between similar projects (some public, some NGO-led) taking place in the same area, giving rise to overlaps and confusion. Nord et al. (2021) similarly found considerable mismatch between messages provided by the various institutions and organisations involved in extension. Kiptot and Franzel (2019) describe the many strengths of an NGO-led 'volunteer farmer–trainer (VFT) approach', but note that proliferation of Kenyan extension providers that wish to reach farmers via the VFTs necessitates better coordination, to avoid conflicting messages that undermine credibility. In Ethiopia, Sime and Aune (2018) identify "inadequate linkage between extension systems, social networks and research projects" as a barrier to the upscaling of sustainable agricultural practices, and also studies from Tanzania have identified weak research–extension–farmer linkages (Mtega & Ngoepe, 2019; Schut et al., 2015).

With proliferation of actors also follows a proliferation of extension methods and tools, and new areas of extension work. Such innovation can be very positive, but scholars have pointed to the value of integrated extension approaches; ones that for example combine technical support with training and networking around value adding and market integration (Ayenew, 2016; Fofana et al., 2020). To do so, it is crucial to take stock of, and combine, different extension methods instead of implementing them in "silos" (Osumba et al., 2021) or "piecemeal" (Yitayew et al., 2021). Likewise, non-state actors can bring new agricultural technologies and knowledge; for example, organic farming methods are not seldom pioneered by NGOs and private companies (Altenbuchner et al., 2016; Hauser & Lindtner, 2016). However, they can also promote technological change that is problematic from a sustainability perspective, such as pesticide use as the foremost crop-protection strategy (Ngowi et al., 2016).

Finally, the outcomes of extension in pluralistic systems are partly a matter of policy design. Not all East African countries have formally adopted national extension policies, which hampers the possibilities for stable and coordinated service offering (Abdu-Raheem & Worth, 2017).[5] Where this has occurred, it has, as noted, generally become mainstream to aspire for more 'participatory' and 'multi-stakeholder' governance, including in policy formulation. This is in line with the idea that AES should be developed with consideration for the sociocultural, -economic and geographical contexts wherein extension will take place (Ariong et al., 2016). Involving small-scale farmers and their organisations helps to ensure that their interests are served and can also be important for restoring trust in the government (Haug, 2016). Unfortunately, participatory *rhetoric* does not guarantee meaningful participation by relevant parties, as exemplified by Ethiopia's PADETES program (Belay, 2003; Tsige et al., 2020). In Uganda, in the design and implementation of the NAADS program "farmers were able to exert an important influence" through various formal and informal mechanisms – and yet, a heavy influence of World Bank rhetoric can be seen in the final product (Parkinson, 2009). Rwamigisa et al. (2018) also criticise the NAADS reform process for being overly driven by donor agendas, and attributes some of its later problems to marginalisation of key domestic actors (including Ministry of Agriculture staff) and failure to build consensus. Joughin and Kjær (2010) note that despite "a long process of programme formulation in which all stakeholders were heard", in the end, ownership of the program was not as encompassing as it had first seemed. More recently however, the development of a new extension policy (passed in 2016) showed signs of successful stakeholder collaboration for evidence-based policy development (Pali et al., 2018). In line with the call by Rwamigisa et al. (2018) for evolutionary (rather than revolutionary) extension

[5] We were unable to access this reference in full, but in their abstract Abdu-Raheem and Worth (2017) state that an"unexpected initial finding was that only three countries in Eastern Africa have legislated (i.e. formally adopted) national extension policies". To our knowledge, the countries in our focal region that have done so are Kenya, Uganda and Ethiopia.

policy reform, the development of NALEP in Kenya also offers useful insights regarding how to employ local, multi-stakeholder pilot projects in the formulation of national policies, specifically regarding how to achieve meaningful community participation in policy planning and budgeting (Anyonge et al., 2001).

4.5 The political economy of extension: confronting interests and ideology

The literature points out many direct and relatively uncontroversial causes of extension weaknesses, such as underfunding, coordination failures, and endurance of problematic 'technology transfer' models. However, some studies also dig deeper into the politics of extension to identify deeper drivers of such phenomena. This is important, as agricultural extension can never be properly understood in the absence of its political-economic context, despite its often technical and non-ideological framing (Cook et al., 2021; De Vries, 1978). Most studies, within the East African context, that critically assess extension and its challenges from such a perspective focus on either Ethiopia (Abi et al., 2019; Adem, 2012; Berhanu & Poulton, 2014; Leta et al., 2018a, b) or Uganda (Danielsen et al., 2014; Joughin & Kjær, 2010; Rwamigisa et al., 2018; Twongyirwe et al., 2020). In both cases, authors highlight the problem of 'politicisation' – utilisation of agricultural extension for political purposes unrelated to agricultural development, such as securing votes, rewarding loyalty, recruiting influential individuals, and exerting state control in rural areas. While such phenomena appear particularly pronounced in these two countries, it should be noted that political and political-economic challenges broadly speaking exist everywhere. For example, Lameck and Hulst (2021) note in Tanzania that despite decentralisation reforms, 'downward accountability' at the local government level remains highly constrained, limiting farmers' influence on extension policies and practices.

In Ethiopia, a body of critical scholarship reveals a long history of extension being used as an instrument of political control and coercion (Adem, 2012; Berhanu & Poulton, 2014; Hailemichael & Haug, 2020; Lefort, 2012; Leta et al., 2018a, b; Regassa et al., 2019; Spielman et al., 2010). This includes a paper on PPT, wherein Nyang'au et al. (2018) note that extension agents"are mostly engaged in delivering political messages and undertaking tasks on behalf of the ruling party, such as collecting taxes under the cover of extension work" (p. 3). Recent years' political upheaval leaves question-marks regarding the current state of affairs, but the challenges are deeply rooted and require substantial reforms both within and outside of the AES itself (Adem, 2012; Spielman et al., 2010). In Uganda, scholars have noted a heavy influence of donor interests and ideology (Rwamigisa et al., 2018) but have also described politicisation of extension associated with the relatively recent advent of multi-party politics (Joughin & Kjær, 2010). The advisory service programme (NAADS) became increasingly politicised as the 2011 national elections drew closer, with Kjær and Joughin (2012:328) describing funds "essentially being distributed as handouts, with all the dependency issues that entailed: basically a political pay-off in terms of support for the ruling elite". AfranaaKwapong and Nkonya (2015) also identify political interference as a major problem for NAADS, including the way that the president publicly criticised and undermined the program after launching the more government-centered 'Prosperity for All' manifesto (AfranaaKwapong & Nkonya, 2015). The "extension chaos" (Twongyirwe et al., 2020) of privatisation, re-centralisation and most recently militarisation is linked to broader political processes and is in itself a source of extension failures (Danielsen et al., 2014; Raile et al., 2021; Rwamigisa et al., 2018).

Politicisation of extension can severely exacerbate the problems of access and inclusivity, by diverting attention and resources away from the beneficiaries and outcomes as defined on paper. For example, Ethiopia's 'model farmer' approach has successfully widened extension coverage in a cost-effective manner, but the selection of farmers warrants critical attention, as the overriding criteria appear to be wealth and political allegiance. The selection process has lacked community participation and is shaped both by the pressure to meet technology diffusion quotas, and the function of the AES to enable surveillance and community policing (Hailemichael & Haug, 2020). The extension system has further consistently promoted technology packages that are poorly adapted to the local agro-ecological and/or socio-economic context. Gebremariam et al. (2021) describe a paradoxical situation where extension packages and advice are better suited to well-off farmers, but because of the political surveillance associated with the formal extension system, it is evaded by wealthier farmers (who can access inputs elsewhere). Poor farmers, meanwhile, cannot 'afford' to evade the extension system even if they find the content to be of limited relevance. In another example, where extension efforts *did* in fact aim to make agriculture more sustainable (resource conserving), the politically motivated tendency to target 'socially connected' farmers reduced their effectiveness (Matouš et al., 2013). A problematic focus on input provision has also been seen in Uganda. The input component of NAADS over time grew to account for almost 80%, "a complete reversal of the original vision" (Kjær & Joughin, 2019). The subsequent Operation Wealth Creation was an even further step in this direction, which shifted responsibilities from experts onto "ex-army combatants and serving army officials who were barely skilled in agriculture" (Twongyirwe et al., 2020:3).

In summary, 'politicisation' of extension is repeatedly presented as a source of problematic outcomes, which often

contradict the alleged intentions of AES. It tends to reinforce a top-down mode of extension focused on generic input-provision rather than locally adapted and responsive *advisory* services. This stands in stark contrast to effective PPT dissemination (see Khan et al., 2014) and the support of ecological intensification more broadly. By comparison there was limited attention to how other interests (e.g. corporate) shape the information and advice that farmers receive. Ngowi et al. (2016) however argue that the growing presence of agro-chemical industry actors risk stimulating increased pesticide use, for example through 'safe use' campaigns, whereas the primary focus of extensionists ought to be advocating non-chemical pest control (Ngowi et al., 2002). This is an issue that warrants increasing attention as growing corporate concentration and power in the global seed and agrochemical industry translates to increasing influence to shape not only agricultural markets and technology pathways but also policy and governance frameworks, in ways that may undermine the goals of equitable, healthy and sustainable food systems more broadly (Clapp, 2021).

5 Discussion and conclusions

Agricultural extension systems have potential to act as forceful catalysts for sustainable agricultural development and improved food security, but there are numerous barriers for this to occur. Our analysis of literature on AES in East Africa aimed at generating insights regarding their current capacity to support upscaling of push-pull technology, with implications for ecological intensification in the region more generally. We recognise that many other factors influence technology adoption, such as availability of relevant inputs (Cheruiyot et al., 2021), compatibility with other farming system components (Muriithi et al., 2018) and structural conditions such as land tenure security (Adamie, 2021). Here we focused on the AES, which has been pointed out as an important roadblock in the literature around PPT. Ecological intensification practices such as PPT tend to be knowledge-intensive, complex and not fully understood, in need of local adaptation, and produce numerous tangible and intangible benefits, some not immediately. They may be labour-intensive, or in any case require reorganisation of farm labour. Therefore, they depend on extension systems that can provide continuous and context-sensitive support, foster social learning and experimentation, seriously engage with existing knowledge and practices, and facilitate collaboration between farmers and researchers in the improving of technologies and solving of challenges. This in turn requires not only new knowledge within the AES, but also systemic changes in the ways that extension workers are facilitated, evaluated and compensated. Against this background, we identified four thematic areas in the academic literature, where interventions and/or further research are needed.

First, universal and continuous access to extension support remain elusive goals, seriously undermining the potential of promising innovations such as PPT to alleviate poverty and food insecurity. As recent evidence has corroborated (Kabirigi, 2022), access is not only a matter of geography and infrastructure, but also of the strength and reach of social networks. Amplifying extension through farmer networks and social learning is important and should be central to ecological intensification efforts – as previously suggested in PPT research (e.g. Khan et al., 2008a, b; Murage et al., 2012) though individual interaction remains important. Gender-sensitive approaches are essential (see also Misango et al., 2022), but we do also caution against static understandings of gender relations, and that fostering intra-household cooperation is key. Important questions remain regarding *who* should be targeted as focal points (e.g. 'farmer-advisors') in the context of PPT; for example, so called 'entrepreneurial lead farmers' with high capacity to learn complicated technologies, or 'ordinary' farmers who tend to be better at influencing their fellow smallholders (Takahashi et al., 2020)? This calls for further inquiry.

Second, there is much hope in the potential of ICTs to enhance extension by transmitting information in new ways, improving coverage and timeliness, stimulating social learning, and changing social norms. This is well founded by research from East Africa as well as other parts of the world (see for example Heong et al., 2021). Still, ICTs' potential to 'revolutionise' agricultural extension (e.g. Mapiye et al., 2021) also need to be tempered (McCampbell et al., 2021; Shilomboleni et al. 2020). They are no silver bullets – they are not inherently inclusive, require contextual adaptation, and cannot replace in-person interaction. Performance tracking and improved supervision of staff via ICTs can be constructive, but the risks of 'workplace surveillance' (see Ball, 2010) ought to also be recognized. We further detect a growing need to coordinate the numerous concurrent ICT initiatives by various AES actors. The proliferation of technologies, applications, platforms and services otherwise risk resulting in overload, confusion, and missed opportunities for synergies. As the impact of ICTs to some extent appears to be technology-specific, we also call for attention to how ICTs are most productively developed and applied with regards to PPT and other similarly complex ecological intensification approaches.

Third, improved coordination of the numerous actors involved in extension is urgent. The pluralistic extension system is likely here to stay, but it cannot deliver on its promises unless its various players are organised and properly incentivised in accordance with the desired outcomes – both in terms of the 'who' and 'what' of extension. There is a tendency for all types of providers to overlook poor farmers and/or remote communities, and as implied by Wafula et al.

(2016), there also are tensions between 'demand-driven' extension and the goal of *sustainable* agricultural development. Some practices which contribute to sustainability may not have obvious appeal to farmers due to their complexity, the nature of the impacts, or simply due to being unknown. Farmers may also be influenced by direct and indirect messaging around 'modern' inputs and practices, intensified by a greater presence of industry actors in the extension landscape (Isgren, 2016; Luna, 2018; Ngowi et al., 2016). All this considered, there is a continued need for states to increase public funding in the agricultural sector and take an active role in extension – even if they no longer have a monopoly on providing the services. The persistent public underfunding of agriculture, and the negative trend in the share of expenditure spent on extension in many SSA countries (Pernechele et al., 2021) requires forceful action. It is also high time for the ubiquitous rhetoric of 'participation' to systematically translate into practice, from policy formulation to implementation and evaluation. Our review revealed a vast amount of knowledge and experience on 'what works' when it comes to participatory approaches, but research attention is needed to support the translation of these insights into systematic and sustained action throughout the AES. There are some promising ongoing efforts (e.g. Gerster-Bentaya et al., 2022) which urgently need to be scaled up and sustained beyond pilot projects.

Fourth and finally, is crucial to recognise that interests and ideologies within and around the AES have a bearing on how extension is designed, funded, and implemented. Even the most promising technologies can be thwarted by an unfavourable political-economic context, as often noted in research on socio-technical transitions (e.g. El Bilali, 2019; Geels, 2019). This is true globally; for example in Southeast Asia, major advances were achieved in the 1980–2000s in terms of scaling up natural pest control in rice through farmer field-school approaches. However, regime changes, political shifts and liberalisation, and the weakening of extension services in the wake of regionalisation policies (Thorburn, 2014) significantly contributed to the loss of these advances, with a subsequent return to pesticides and a pest resurgence (Bottrell & Schoenly, 2012; Prihandiani et al., 2021). Today, government officials promoting pest management alternatives are outnumbered by pesticide sale agents in many Asian countries (Heong et al., 2021) and similar concerns have been reported in SSA (Isgren & Andersson, 2021). It is clear that beyond reformulated *policies*, addressing extension weaknesses requires grappling with *politics* and various vested interests, as previously argued by Cook et al. (2021). In the current era, these include not only governments and donors but also powerful corporate actors. There is always potential for incremental improvements and local success stories, and many are cited here, but broadly scaling up promising ecological intensification practices calls for substantial reforms or 'transformative socio-economic changes' (Kremen, 2020). Political-economic forces and cultural norms that perpetuate emphasis on standardised input packages and one-directional knowledge transfer in agricultural extension must be challenged. This means both confronting problematic forms of 'politicisation' and public funding priorities, and scrutinising the role of profit-motivated actors in AES. Only then can extension agents be expected to continuously engage with small-scale farmers on basis of needs, suitability and interest – not political motives, marketing of products, or farmers' ability to pay. In the meantime, those aspiring to scale up practices such as PPT must strategically navigate existing extension landscapes. This means utilising opportunities that arise thanks to today's complex "institutional bricolage" (Moorsom et al., 2020) whilst seeking inroads to incorporate ecological intensification principles and practices into public extension systems.

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