Available Online at ESci Journals
International Journal of Agricultural Extension
ISSN: 2311-6110 (Online), 2311-8547 (Print)
http://www.escijournals.net/IJAE

SUPPORTING FARMERS IN THE TRANSITION TO AGROECOLOGY TO PROMOTE CARBON SEQUESTRATION FROM SILVOPASTORAL SYSTEMS

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ABSTRACT

Silvopastoral systems, or silvopastures, have the potential to provide a wide range of ecosystem services to benefit the environment and society in relation to climate change, in particular carbon sequestration. However, being considered highly diversified and integrated systems, silvopastures present several challenges in the evaluation of their performance to support their adoption in different environmental contexts with the purpose of increasing carbon sequestration from agroforestry. While such evaluations and predictions of carbon sequestration potential can be achieved by researchers with long-term experimental studies and scenario-based modelling, farmers and land managers may need sufficiently accurate yet simplified methodologies to estimate the impact of land use and land use changes from forestry (LULUCF). This can be achieved with decision-support tools and participatory work where farmers and researchers engage in sharing and co-creating knowledge on best agroecological practices. This work sets out to review the current knowledge on carbon sequestration from silvopastures and the state of the agroforestry sector in the UK. It then proposes a methodology to integrate agroecological practices and knowledge generated using scenario-based LULUCF modelling to identify practical farm management strategies. It highlights potential barriers to and drivers for innovation in the UK agroforestry sector, including the impact of farmers' attitudes to climate change and silvopasture, and the impacts of networks of influence, community of practice, and the current provision of extension and advisory services. Finally, it illustrates how a decision-support system tailored for the agroforestry sector can benefit farmers in their transition to silvopastoral farming systems by adopting agroecological principles.

Keywords: silvopasture, carbon sequestration, land use changes, farmer engagement, decision support tools, knowledge integration, agroecological transition.

INTRODUCTION

In the United Kingdom (UK), agriculture accounts for about 7% of the total greenhouse gas (GHG) emissions (DEFRA, 2016) and the country is committed to reduce these emissions by 80% below the 1990 value (United Kingdom Parliament, 2008). The removal of GHG emissions, especially CO_2 from the atmosphere due to land-use practices could potentially be used as a mitigation option by implementing agroecological systems. Agroecology is defined as the discipline that addresses practical aspects of resilient food production and natural resources management, their environmental impact as well as the governance and socio-economic challenges facing current food and farming systems (Altieri, 2002; Wezel *et al*., 2009; TWN & SOCLA, 2015). High-performing agroecological systems have the potential to ensure productivity and biodiversity by adopting climate-friendly practices (Pretty *et al.*, 2011; Bohan *et al.,* 2013). Agroecological practices favour the protection of soil carbon and carbon sequestration in vegetation biomass and therefore have great potential for climate change mitigation (Wibbelmann *et al.,* 2013), significantly reducing the carbon footprint especially in smallholder farming (Rakotovao *et al.,* 2017). Agroforestry can be considered among agroecological systems because it uses complementarities and synergies combining crops, plants, trees and animals within diverse spatial and temporal settings (Altieri *et al.,* 2015). Silvopasture, which is a type of agroforestry

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system that combines grazing stock and trees on the same land base, can provide high biodiversity, efficient feed conversion and good animal welfare, and mitigate soil erosion and climate change (Broom *et al.,* 2013). However, when considering scale, the level of system change that would be needed to implement agroecological practices in agroforestry systems is high and the uptake of such systems is currently low in Europe (Wezel *et al.,* 2014). This is also due to the complexity and long-term risk management needed in such highly diversified farming systems and difficulties in integrating scientific advances and practical support for farmers to design and implement silvopastoral practices (Lovell *et al.,* 2010; Torralba, *et al.,* 2016).

The three dimensions of agroecology, i.e. movement, science, practice, described by Wezel *et al.* (2009) are well reflected in the recent interest in silvopastoral systems and, more widely, in agroforestry to promote diversified and sustainable farming that contributes to mitigate climate change. Carbon sequestration from agriculture and agroforestry further contributes to reducing the carbon footprint of these production systems. However, challenges remain in the improvement of the accuracy of carbon accounting in complex systems, and the subsequent impact on promoting and supporting the transition to agroecological practices, as well as integrating these into agroforestry-adapted future policy. In order to understand how scientists can support farmers and land managers in the transition to agroecology to promote carbon sequestration in silvopastoral systems, we need to acknowledge the contribution of agroforestry, the methodologies used to estimate the impact from Land Use and Land Use Changes from Forestry (LULUCF), and the potential of agroecological practices to increase carbon sequestration from silvopasture.

Carbon sequestration from agroforestry (UK): The role of land use systems in stabilizing the CO_2 levels and increasing the carbon (C) sink potential has attracted considerable scientific attention, especially after the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC, 2015). The UK reports GHG emissions and carbon stock changes for the LULUCF sector as part of its national GHG inventory. The LULUCF sector is unusual in that it is the only sector of the inventory which can report removals as well as emissions for GHGs. LULUCF removals occur when the carbon stocks of soils and biomass increase, while emissions occur when carbon stocks decrease, or when the non-carbon dioxide GHGs methane and nitrous oxide are released from soils or biomass as a result of change in land use or management or fires (DEFRA, 2016).

Agroforestry is one of the most important land use systems practised in diverse ecoregions around the world and have a special relevance within agroecology. These woody perennial-based land use systems have relatively high capacities for capturing and storing atmospheric CO_2 in vegetation, soils, and biomass products. Agroforestry in the UK is developing along two lines: silvoarable systems where rows of trees are intercropped with arable crops and silvopastoral systems where stock graze on pasture between widely spaced trees. Although both systems are not yet practised in a great extent, its role in reducing C emissions and promoting carbon sequestration has been recognised through various policy schemes at national and European level (Fornara *et al.,* 2017; Hart & Baldock, 2011). Silvopastoral systems have the potential to provide a wide range of ecosystem services to benefit the environment and society in relation to climate change, in particular carbon sequestration (Cardinael *et al.,* 2017; Kumar & Nair, 2011; Olave, 2016; Wilson & Lowell, 2016). In order to promote the adoption of farming practices that increase carbon sequestration at farm level, we need to provide farmers and land managers with tools that are user-friendly and scientifically accurate. This work sets out to highlight possible obstacles in the transition to agroecology in silvopastoral systems and proposes a methodology to support farmers in their transition by adopting a practical focus grounded on improved carbon accounting modelling.

Potential barriers to transition: National Adaptation Strategies to address the impacts of climate change are implemented in all European members states, but results may vary, in particular in highly diversified sectors such as the agriculture and forestry. Challenges include the uncertainty regarding scientific knowledge on carbon balance and accounting methodologies, coupled with the difficulty in achieving successful multi-actor approach activities involving government agencies, local agencies, researchers and private sector, and in establishing an effective knowledge transfer network, as illustrated in Figure 1 (Biesbroek *et al.,* 2010). Long *et al.* (2016, p.17) identified a series of barriers to the adoption of climate-smart agricultural (CSA) technology.

These include: *"low awareness of CSA and inaccessible language, high costs and long return on investment (ROI) periods, lack of verified impact of technologies, regulatory and policy issues, hard to reach and train farmers, Research and Development (R&D) and policies do not match to 'on-the-ground' reality, low consumer demand, and unequal distribution of costs/benefits across supply chains."*

Furthermore, supporting farmers in the transition to silvopastoral systems can face obstacles linked to the potential lack of trust in government advice and reluctance in taking a financial risk, and the fragmentation of extension services provided in the United Kingdom. Lacking in trust of scientific evidence regarding climate change and carbon accounting can be reflected on difficulties for farmers and land managers to access scientific knowledge and body of academic literature on climate studies, largely inaccessible to the general public, and the perceived lack of transparency and clarity in such information, e.g. adopting overly technical terminology (Hofmann *et al.,* 2011). Although there have been significant steps in promoting access to scientific knowledge to the wider public, e.g. Open Access publications, knowledge brokerage events, transition in farming systems can be seen as a great financial risk and motivations to adopt innovative practices in the farming sector can be primarily economic, then followed by the improvement in management practices, and then market pressure (Barnes *et al*., 2010). In the context of whether the financial burden is real or perceived, practitioners need tools that are specifically adapted to agroforestry which easily identify practices and economic trade-offs to support them in the decision-making process. However, it is difficult to include socio-economic trade-offs because they can be very context-specific in the farming sector and in particular in agroforestry, which is a highly diversified type of farming (Paracchini *et al.,* 2008; de Boer *et al.,* 2011; Vellinga *et al.,* 2011, Wallach *et al.,* 2016). The majority of studies on impact assessment and indicators used in agroforestry do not include economic variables (Fargerholm *et al.,* 2016).

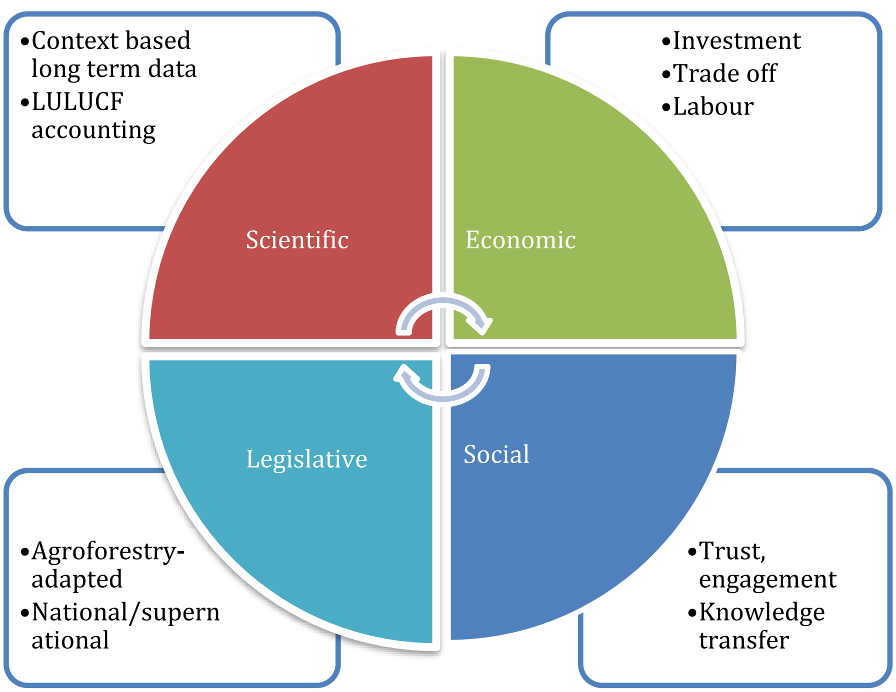

Figure 1. Main challenges associated with transition to complex systems, such as agroecological systems.

Promoting the adoption of agroecological practices in silvopastoral systems can have challenges associated with the promotion of innovation more generally. Farmers' attitudes to innovation can be influenced by several factors, such as personal beliefs, family values, and other external actors like extension officers, experts and also the media. In a recent British study on livestock farmers' attitudes to climate change, Burbi *et al.* (2016, p.467) found that a *"proactive attitude seems to be hindered by confusion and lack of confidence in* *governmental strategies to disseminate scientific knowledge."* While extension officers provide specific, technical advice to farmers and land managers (Takemura *et al.,* 2014), the funding and support to advisory and extension services in the United Kingdom have been progressively and continuously reduced in the past 3 decades, creating a highly fragmented sector with great variability in the efficiency and impact of these services (Swanson & Rajalahti, 2010). Studies suggest that focusing exclusively on technical advice may not effective in promoting innovation and transition in farming (Islam et al., 2013; Llewellyn, 2007). Advisory, extension services and knowledge transfer activities need to include information on cost-effectiveness and estimates of the socio-economic impact of changes in farming practices (Kings & Ilbery, 2010) and need to take into account farmers' attitudes and perceptions of innovation (Mills *et al.,* 2013). This is particularly relevant when addressing carbon sequestration and climate change related topics because of the difference in aims and objectives between researchers, farmers and land managers, and policy-makers, resulting in potential uncertainty over the long-term impact of the transition and the best risk management option farmers ought to take (Burbi & Olave, 2017).

PROPOSED METHODOLOGY

Among the advantages of agroecology are its adaptability, site-specificity and the fact that it promotes the integration of scientific and traditional knowledge (Sarandón & Flores, 2014). These three characteristics make agroecology likely to be taken up by farmers (Saj *et al.,* 2017). Participatory Action Research (PAR) is widely accepted by the scientific community as a multi-actor approach to engage with different groups of stakeholders with differing aims and knowledge(s) (IFAD, 2009; Pretty & Buck, 2002). This approach is particularly effective in agriculture and forestry extension services because it fosters improved communication and knowledge integration, leading to a collective process with practical problem-solving activities (German *et al.,* 2012; Klerkx et al. 2012; Le Gal et al., 2011; Xu *et al*., 2011; Jacobi *et al.,* 2016). In spite of the possible biases and limitations listed by Neef & Neubert (2011), e.g. context-dependent results, differing goals, power relationships, PAR creates a process that allows for greater engagement with stakeholders (Mapfumo *et al.,* 2013; Oliver *et al.,* 2012). In the case of farmers, the process helps to build trust and they are then more likely to adopt innovative practices as a result from improved communication with researchers and other experts, in particular when considering the economic impact of transition and the potential barriers represented by the lack of an agroforestry-adapted environmental policy and long-term political strategy integrating agriculture, agroforestry and climate change mitigation (den Herder *et al*., 2017; Emery & Franks, 2012; Mosquera-Losada *et al*., 2015).

The methodology we propose is grounded in the concept of knowledge integration as described by Newell *et al.* (2005) and the provision of evidence-based scientific advice using farmer-friendly indicators to design a decision support tool that provides practical advice to farmers and land managers wanting to improve carbon sequestration from silvopasture or transition from grassland-based to agroforestry systems. The framework is structured in three phases: i) Initially, more comprehensive and accurate LULUCF models can provide the evidence-base to support the transition to agroforestry systems with greater carbon sequestration potential; ii) Subsequently, specific silvopastoral practices that increase carbon sequestration can be selected based on the following criteria: agroecological principles, potential to sequester carbon and confidence of evidence-base to support it; iii) Finally, user-friendly indicators can be identified through participatory work with farmers and land managers to design and implement a decision support tool adapted to silvopasture and carbon sequestration. This last phase will lead to the possibility of expanding the framework to integrate a science-based farm management assessment and monitoring with economic and legislative contexts.

Phase 1: Improvement of LULUCF accounting could provide more accurate estimates of the potential for carbon sequestration based on land types and land use. On the one hand, this would allow for more accurate prediction of future scenarios in case of land use changes, providing evidence to support policy making (Rittenhouse & Rissman, 2012). On the other hand, this would also allow for the design and implementation of decision-support tools that are more accurate and better reflect the impact of agroecological land management practices on carbon sequestration (Mosquera-Losada *et al.,* 2017). Recent studies have shown the benefit to GHG mitigation of combining tree, hedgerows and farming production in specific systems using life cycle assessment techniques (Nguyen *et al*., 2013, Black *et al.,* 2014). However, as an example, some activities not included in the GHG inventory and LULUCF accounting are fences replaced by hedges, development of scrub, hedge management and C dynamics in soils below hedges. Therefore, this phase is expected to generate data on future scenarios based on more accurate LULUCF accounting of carbon balances under different land managements. This work is essential to bring clarity using appropriate and standardised agroforestry descriptions (Palma *et al.,* 2015) and including economic considerations into the definition of agroforestry categories with the purpose to build more accurate scenarios relevant to the sector and, therefore, more likely to be useful from a practical, farmer's perspective (Keesman *et al.,* 2011; Luedeling *et al.,* 2014).

Phase 2: The five main agroecological principles for sustainable livestock farming are: 1) integrated animal health management; 2) reducing external inputs; 3) re-coupling carbon (C), nitrogen (N) and phosphorous (P) cycles; 4) preserving and using biodiversity; and 5) increasing systems diversity and resilience (Dumont *et al.,* 2014). This phase will list specific agroecological practices in silvopasture and assign scores based on their potential to sequester carbon and on-farm empirical studies. As examples, soil carbon stocks at 1 m depth tend to be greater under the tree canopy, with 50.2 Mg $ha^{-}1$ at 2 m from cork oak and 26.5 Mg $ha^{-}1$ at 15 m (Howlett *et al.,* 2011). Soil aggregates also play a significant role in C stocks in silvopastoral systems, where a greater proportion of micro-aggregates are found. Micro-aggregates have been found to be more stable than macro-aggregates in retaining carbon. Therefore, it is reasonable to expect that carbon sequestered in micro-aggregates in soil managed under silvopastoral farming conditions is more stable and likely to contributes to long-term C stocks. However, soil composition and C saturation rates also need to be considered (Fornara *et al.,* 2017). A review of all agroecological practices in silvopasture that increase carbon sequestration will allow the initial assessment of the system based on criteria, such as soil characteristics, tree density, stocking rate, grazing patterns and pasture composition.

Phase 3: An indicator-based decision support tool will be designed based on data obtained from Phases 1 and 2 to provide farmers and land managers with practical solutions to implement and monitor their transition to more carbon-friendly systems. Sustainability assessment tools can adopt a variety of methodologies, e.g. indicators and indices, product-related assessment, integrated assessment (Ness *et al.,* 2007). The challenges in this case are related to time and resources available to assess and monitor the farm, and the diversity of systems in terms of production, location, soil properties, and climatic variations. Therefore, rapid indictor-based assessment tools are the preferred methodology to allow for a context-specific assessment that is both accurate and user-friendly (Burbi *et al.,* 2016). Indicator-based tools are supported by scientific evidence, yet easy-to-use, e.g. soil health indicators (Nicholls *et al.,* 2014). They allow for regular and context-specific regular assessment of the system (Mwongera *et al*., 2017) and as a result they have the potential to promote greater researcher-farmer engagement and aid long-term evaluation and monitoring of the carbon balance in silvopastures. This approach is in line with what suggested by Csikvari *et al.* (2017) in a recent review of tools available for the design and management of agroforestry systems, which highlighted the lack of knowledge by farmers of the wider benefits of agroforestry, including carbon sequestration. The authors also highlight the difficulty in matching scientific knowledge with current ecological and economic needs of farmers and land managers and how tools need to support farmers in the identification of key practices to implement on-farm, being user-friendly and aimed at the adoption of a more strategic long-term approach to farm management to increase carbon sequestration from the whole system.

ADVANTAGES

Drivers for transition: Knowledge integration is key to the promotion of innovation among farmers. However, this process can be difficult to achieve because farmers' knowledge tends to be based on anecdotal evidence and practical experience and therefore it is difficult to integrate with scientific knowledge (Raymond *et al.,* 2010; Sutherland et al., 2013). Participatory learning processes where farmers' knowledge is valued have the potential to foster on-farm innovation and increase the adoption of agroecological practices (Louah *et al.,* 2017). The methodology described aims at fostering knowledge transfer between researchers and farmers, effectively creating synergies between the different actors involved. On the one hand, scientific knowledge can be communicated effectively to farmers and land managers who, on the other hand, will have the opportunity to contribute by feeding back on the most successful implementation strategies to promote carbon sequestration by the transition to silvopasture, valuing farmers' knowledge and contribution to the process (Schöll & Binder, 2009; Virji *et al.,* 2012; Castellanos *et al.,* 2013). Farmers tend to rely on peer-to-peer exchange of experiences to acquire knowledge and therefore, the networks of influence in which farmers operate have a great impact on the adoption of innovation (Oreszczyn *et al.,* 2010; McKenzie, 2011; Schut *et al,* 2015). By promoting collaboration between researchers and farmers, the methodology proposed is expected to be more successful in transferring knowledge to support the transition to a more sustainable system, without assuming that financial incentives will be the only effective drivers for change (Sereke *et al*., 2016). It represents a means to foster farmer-driven innovation capitalising on the strengthening of synergies with extension services and researchers.

Perceptions vs Reality: In spite of the growing interest in carbon sequestration from the farming and agroforestry sectors, farmers' attitudes to climate change related issues could be influenced greatly by their perceptions of risk and of clear long-term benefits from the transition to silvopasture. Farmers appreciate flexibility in the management of their agri-businesses and the policies that impact the sector (Jones *et al.,* 2013). However, they are also more likely to adopt innovative practices that have a perceived low economic risk or have multiple benefits (Burbi *et al.,* 2016; Khatri-Chhetri *et al.,* 2017), especially when clear short-term benefits and income generation are presented, rather than long-term impacts (Tittonell *et al.,* 2012). This may create a challenge in the design of decision-support tools that are accurate, yet flexible and comprehensive, address carbon sequestration from the environmental, socio-economic, and potentially also legislative point of view, as shown by studies on complex socio-ecological systems (Bodin & Tengö, 2010; Feola & Binder, 2010; Cornell *et al.,* 2013).

The proposed methodology focuses on evidence-base practical advice on silvopastoral systems using a farmer-friendly tool to identify the practices more beneficial in terms of carbon sequestration and aid the transition to a more sustainable natural resources management system and its monitoring. By integrating scenario-based modelled data with context-specific knowledge, this approach is likely to be a flexible solution to promote the transition, especially in a highly diverse sector such as agroforestry (Fischer & Glenk, 2011; Nicolosi & Feola, 2016).

CONCLUSION

Decisions to adopt or abandon silvopastoral systems to promote C sequestration are shaped by several factors (e.g. scale, profitability, labour requirements, trade-offs) shown to be significant in the agroecological transition process. Discussion of these factors centres on the role of scientific evidence and key categories, specifically, farming type, management practices and community characteristics. In addition, these factors are both challenges and opportunities for scientists, environmental professionals, farmers, land managers and policy makers to consider when planning and implementing agroecological systems such as agroforestry and silvopastoralism in particular. Hence it is suggested that the transition to agroecology could realistically be achieved by implementing a decision support tool where the benefits of agroforestry systems to store carbon can be incorporated and information and open communication links as main drivers are considered in adoption.

ACKNOWLEDGEMENTS

This work has been presented at the 13th Symposium of the International Farming Systems Association (IFSA), held at the Mediterranean Agronomic Institute of Chania (MAICh), Crete, Greece, 1-5 July 2018. The authors would like to thank the IFSA Symposium organisers.

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