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Original Article

A Framework for Interdisciplinary Research Methodology in Agroforestry: A Review

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ABSTRACT

This paper provides a framework for interdisciplinary research (IDR) methodology in agroforestry, motivated by a general belief that by drawing information from different fields and employing different methodologies, a broad understanding of an existing issue can be achieved. Literature from four scientific paradigms was reviewed to recommend a suitable paradigm for IDR in agroforestry. We promote a pluralistic approach around the concept of 'what works' such that agroforestry research and extension focus on applications of techniques to solve a problem. The study suggests a framework for IDR in the context of developing countries by modifying an existing Methodology for Interdisciplinary Research (MIR) framework that was developed to help cross disciplinary borders, especially those between the natural sciences and the social sciences. The existing framework is however limited to real-life applications in teaching and research. We contend that agroforestry research should be seen to benefit the rural poor, foster innovation and farm productivity to feed the growing world population and help farmers adapt to the changing climate. The suggested IDR framework therefore caters for extension and feedback mechanisms, that appear to be the missing link between research and education. The new framework further provides for social relevance and the generation of data for informing policy decisions relating to sustainable agriculture. The paper also highlights the main barriers and opportunities for implementing IDR in agroforestry. The current and future global complex agricultural challenges require experts with interdisciplinary experience. Therefore, interdisciplinary research in agroforestry must increasingly become the standard rather than the exception because the approaches needed and the implications of agroforestry research are by their very nature interdisciplinary.

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INTRODUCTION

Current global challenges such as water scarcity, food insecurity and urbanization, involve the interaction between humans and their environment rendering a single disciplinary approach inadequate to solve them. The study of the interaction between humans and their environment requires knowledge and research methodology from different disciplines (Tobi, & Kampen, 2017) such as the natural sciences, the social sciences, and the humanities (Kagan, 2009; Rutting et al., 2016). There has been a longstanding call for interdisciplinary research involving the social and natural sciences to manage complex societal issues (Das, & Paital, 2021; Fischer et al., 2011; German et al., 2010). This is mainly because most real-life problems are multifaceted and complex to be dealt with, with an un-interdisciplinary approach (Rutting et al., 2016). The collaboration between natural and social sciences is needed due to an increasingly intricate interweaving between the socio-economical context that drives the people living in the environment and their impact on the biophysical environment (Fischer et al., 2011).

Over the years, different forms of collaboration have been distinguished with terminologies such as multidisciplinary, interdisciplinary and transdisciplinary research. Multidisciplinary research is research that involves more than one discipline but without integration of disciplinary insights (Rutting et al., 2016). Interdisciplinary research has operationally been defined as a mode of research by teams or individuals that integrates perspectives/ concepts/ theories and/or tools and techniques and/or information/data from two or more bodies of knowledge (National Academies, 2005). Danermark (2019) presents a more critical realist definition of interdisciplinary research as any study or group of studies undertaken by scholars from all relevant levels that are needed to answer the research question. It requires the interaction of two or more disciplines in: the communication of ideas and organization of knowledge, using methods, procedures, theories and data between members of a group or by an individual to solve a single problem (Butler, 2011). On the other hand, transdisciplinary research is taken as a higher form of interdisciplinarity in the sense that it addresses more complex problems that cut across a large section of societal sectors and multiple stakeholders. It is where different academic disciplines work together with non-academic collaborators to integrate knowledge and methods to develop and meet shared research goals (Hirsch-Hadorn et al., 2008; Kelly et al., 2019). Although these terms can theoretically be distinguished, in practice researchers use these concepts interchangeably – sometimes within the same research project. This paper focuses on interdisciplinary research in agroforestry– involving knowledge integration from different disciplines in solving a common problem.

Transcending the social and natural science divide throws open the field of inquiry and the range of possible solutions (Bromham et al., 2016). For example, many of the great research triumphs, such as human genome sequencing, the "green revolution," and manned space flight are products of interdisciplinary inquiry and collaboration (NationalAcademies, 2005). Elsewhere, IDR has been used to establish a linkage between socio-economic factors and land-cover changes in the marginal rural landscape of the German highlands (Hietel et al., 2005), which generated a better

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knowledge of land-cover history. It has also been used to study the management of infectious animal and plant diseases in the UK (Wilkinson et al., 2011). Another project conducted an interdisciplinary assessment of alternative food networks in Italy (Corsi et al., 2018). One of the fundamental outputs of the project was that economists became more aware of the social implications of transactions and were thus spurred to explicitly include symbolic and intangible attributes of food as determinants of consumers' preferences in their empirical models. This is contrary to a widespread view that economists only deal with monetary variables.

In Africa, IDR has been applied in the conservation and use of the wild populations of *Coffea arabica* in the montane rainforests in Ethiopia (Callo-Concha et al., 2017). However, the study was both inter and transdisciplinary, considering ecological and socioeconomic aspects, and involving stakeholders at local, national and international levels. To address the complexity of food systems in developing countries, a study conducted an interdisciplinary and triangulation analysis of divergent conceptual frameworks (Foran et al., 2014). The analysis found notable tensions and synergistic interactions between agroecology, agricultural innovation systems, social-ecological systems, and political ecology. While existing institutional structures and practices to support interdisciplinary research are still developing (Kelly et al., 2019), there is a great need for the science workforce to collaborate across cultural backgrounds and disciplines (Borrego, & Newswander, 2010). IDR has been highly regarded and predicted as an important factor in future research (Rutting et al., 2016).

Purpose of Interdisciplinary Research

Interdisciplinary research (IDR) integrates concepts and information from two or more bodies of knowledge (Porter et al., 2007). It is suitable for addressing complex problems, especially where both human and natural components exist and interact (Fischer et al., 2011; Frodeman, 2011; Rutting et al., 2016). The purpose of IDR is to provide a framework across multiple disciplines (Porter, & Rafols, 2009) and allow an improved understanding of perceived relationships between variables (Neuman, 2014). IDR also increases the policy relevance and impact of research (Wilkinson et al., 2011). Interdisciplinary research is motivated by a general belief that by drawing information from different fields and employing different methodologies, a broad understanding of an existing issue can be achieved (Rutting et al., 2016). The choice for IDR is often driven by the inherent complexity of nature and society, the drive to explore basic research problems at the interfaces of disciplines, the stimulus of generating technologies and the need to solve societal problems (Rutting et al., 2016). There have also been cases where interdisciplinary approaches to research have been adopted when the traditional disciplinary approaches no longer adequately answered research questions (Butler, 2011).

Interdisciplinarity in Agroforestry Research

Interdisciplinary research in agroforestry is premised on the ever-growing societal desire to attain agricultural sustainability (Hanson et al., 2008) rather than simply increased production. For agroforestry, sustainability refers to the concept that production can occur on a given land management unit on an indefinite basis. For example, while the use of inorganic fertilizers can increase production over a short period, it is regarded unsustainable given the short period of fertilizer efficiency, and the negative land and environmental effects associated with the use of inorganic fertilizers. It has been argued that thinking beyond biophysical technologies could foster farmer institutions to adopt sustainable agricultural technologies (Descheemaeker et al., 2013) and facilitate natural resource management and development practice (German et al., 2010). Failure to incorporate the views of the farmers excludes them from the scientific discourse of agroforestry and from shaping its outcomes. Indeed a significant barrier to addressing farmers' problems is that farmers think in interdisciplinary terms, while professionals are still ruled by

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disciplinary boundaries (Galmiche-Tejeda, 2004). Therefore, researchers need to come up with innovative technologies aimed at adaptive management of farming systems rather than increased production (Vavra, 1996). This will require researchers to build collaborative relationships and develop a shared language and perspective beyond disciplinary boundaries.

Interdisciplinary research (IDR) is suitable for addressing modern requirements for sustainable agriculture given the complex nature that combines social and environmental factors (Morse et al., 2007). In addition, IDR is useful in providing a valuable opportunity for engagement with the user communities of the research thus making it socially relevant (Lowe, & Phillipson, 2006). Low engagement with user communities (for example farmers) often results in research outcomes that lack sufficient relevancy to the intended user. The primary users of agroforestry research, think from a cross-disciplinary perspective about their enterprises and not simply distinct 'silos' (Galmiche-Tejeda, 2004). Where traditional agroforestry research is conducted, for example, collection and analysis of tree management and associated crop yield data may appear acceptable to the research community, but it may not be suitable to the farmer for social reasons not researched in the study.

IDR provides a valuable opportunity for engagement with the user communities of the research, thus making it socially relevant (Lowe, & Phillipson, 2006). Low engagement with research beneficiaries often results in research outcomes that lack sufficient relevancy to the intended user community. Agroforestry researchers must therefore take more steps towards integrating social, cultural, and political lines of inquiry into their core mandates to more effectively address the needs and realities of vulnerable communities. It is not surprising that international institutes for agricultural research such as the members of the Consultative Group on International Agricultural Research (CGIAR) have already adopted a changed discourse on farmers' knowledge by negotiating space for interdisciplinary collaboration (German et al., 2010). However, there is no documented scientific paradigm alignment and framework for interdisciplinary research methodology in agroforestry, a gap this current review seeks to address.

INTERDISCIPLINARY RESEARCH (IDR) METHODOLOGY

Scientific Paradigms in IDR

A paradigm can be defined as a general organizing framework for theory and research that guides the orientation to inquiry including what questions to ask, what methods to use and what knowledge claims to strive for (Morgan, 2007). It is generally a set of assumptions, values, methods, theories and practices shared by a certain community of scientists. Paradigms have ontological and epistemological positions that contribute to how research is conducted, data analysed and findings presented (Rutting et al., 2016). While paradigms do not necessarily govern exactly which types of data or tools for data analysis should be used, they can greatly influence the way tools are used and analysis is done (Neuman, 2014). Stating a knowledge claim means that researchers start their inquiry about how and what they will learn. There are four main schools of knowledge claims within the sciences and social science, namely: positivism, constructivism, advocacy/participatory and pragmatism (Lenzholzer et al., 2013) summarized in Table 1 below.

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Table 1: Categorization and Summary of the Major Scientific Paradigms

Paradigm	Positivism	Constructivism	Advocacy	Pragmatic
Aim	Determinative, theory verification	Subjective understanding, theory generation	Political, change-oriented	Problem centred, practice-orientated
Ontology	Reality is measured	Reality is constructed	Reality is constructed	Reality is discernable but not perfectly
Epistemology	Findings are true and value-free.	Findings are constructed and value-laden	Findings are constructed and value-laden	Findings are applicable, value-aware
Methods	Quantitative	Qualitative	Qualitative	Quantitative and qualitative

Adapted from (Creswell, 2018)

Positivism is predominantly associated with natural science or quantitative social sciences (Aboelela et al., 2007; Lenzholzer et al., 2013) and is based on the belief that an absolute truth can be found and that a single reality exists that is measurable (Healy, & Perry, 2000). It is a representative of pure science that uses stringent quantitative data collection methods to test specific hypotheses or research questions constituted by specific variables (Lenzholzer et al., 2013). It is based on careful observation and measurement of the objective reality in the world. The hypotheses are tested rigorously and then verified or falsified leading to formally considered 'absolute truths' (Fischer et al., 2011). Research conducted within the positivist paradigm is said to be 'value-free' in that the position or values of the researcher do not impact how the research is conducted.

Constructivism also referred to as interpretivism or naturalism has its focus on qualitative research in social science (Petersen, & Gencel, 2013). It is a mode of inquiry in which reality is experientially based, and historically shaped, and its understanding is only relative (Aboelela et al., 2007; Lenzholzer et al., 2013). The major aim of this form of inquiry is to seek an understanding of the world in which the researchers are operating and typically generate multiple views about complex subjective topics (Schwartz-Shea, & Yanow, 2012). The underlying ontology is that reality is constructed based on attitudes, beliefs, interactions and experiences within a specific context (Lenzholzer et al., 2013). The goal of the research is to rely as much as possible on the participant's view of the situation being studied. Constructivists do not start with a theory but use an inductive method to generate theory or meaning. Thus, researchers must focus on the processes of interaction among individuals and on the specific contexts in which individuals live and work, and recognize that the researcher's background shapes their interpretation. Research conducted within the constructivist paradigm tends to focus on ideological and subjective topics rather than topics associated with production or economics. The main criteria in constructivism are authenticity, originality, credibility, transferability and dependability.

Advocacy or participatory paradigmatic position is associated with critical theory and is also referred to as a transformative-emancipatory perspective (Lenzholzer et al., 2013). Research within the advocacy paradigm is typically focused on social justice and equality type of issues to advocate for marginalized groups on topics within the political, ethnic or gender issues (Farley et al., 2010). Often, the researcher helps to 'voice' the (often marginalized) research participants of the research to bring about changes in actual situations and raise awareness of the participants. The research is qualitative and builds on the constructivism paradigm in that the researchers advocate for the participants they study; hence the research is value-laden and results are influenced by the beliefs and perspectives of the researcher.

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Pragmatism is recognized as the middle ground between positivism and the qualitative-orientated paradigms (Johnson, & Onwuegbuzie, 2004). Pragmatists have a pluralistic approach around the concept of 'what works' such that the focus of the research is on applications of techniques to solve a problem. Instead of the method being important, the problem is the most important, and researchers use all approaches to understand the problem. In other words, they are "free" to choose the methods, techniques, and procedures for collecting and analysing data rather than subscribing to only one way. This is the foundation of many studies that have combined multiple approaches. Porter et al. (2007) suggest that interdisciplinary research should be defined by its ability to borrow from other fields, particularly in the area of tools, methods, concepts, models and paradigms which is also in keeping with a pragmatic research approach. It has been emphasized that research quality in qualitative research, it is more important to select appropriate methods rather than be governed by a particular theoretical position.

In pragmatist mixed methods procedures the underlying assumptions may be mixed (Creswell, 2018; Lenzholzer et al., 2013). A pragmatic position has practicality, is contextually responsive and has a degree of consequence such that the researcher is aware of and understands the demands, opportunities and constraints within which the inquiry is taking place (Greene, 2008). Knowledge claims from a pragmatist perspective are based on factors including accuracy, scope, consistency, simplicity and comprehensiveness. The pragmatic paradigm has been criticized by some scholars because it tends to avoid philosophical issues (Johnson, & Onwuegbuzie, 2004). Pragmatic research typically aims to ground the methods of inquiry and reporting in the nature and context of the phenomena being investigated.

PARADIGM RECOMMENDED FOR IDR IN AGROFORESTRY

Agroforestry research always occurs in dynamic social, historical, political and biophysical contexts within which it may be inappropriate to take a unidirectional philosophical divide. To generate practical outcomes, agroforestry research should be conducted within the pragmatic paradigm. With a pragmatic philosophical approach, assumptions are less important than ensuring the study meets its practical demands regarding data collection and interpretation (Tobi, & Kampen, 2017). Therefore, from the pragmatic position, potentially contradictory ontological and epistemological assumptions are less important than situational responsiveness. This would ensure that the study is more focused on achieving the practical outcomes intended while designing the study. Pragmatic research has great appeal because it provides the researcher with the scope to find methods that are best suited to answering the question, adopting a 'what works' approach.

Pragmatists embrace the use of both qualitative and quantitative research methods and recognize the limitations of both approaches in being able to address research questions (Fischer et al., 2011). Therefore, interdisciplinary teams need to be pragmatic since the research questions and hypotheses agreed on take the lead in the study design instead of traditional approaches. However, Tobi, & Kampen (2017) warn that the so-called ''paradigm war'' between neopositivists versus constructivists within the social and behavioral sciences may complicate pragmatic collaboration. This is because natural sciences tend to adopt a positivist, reductionist approach looking for the 'truth', while in social science, a more social constructivist approach is taken. These perceived differences lead to barriers as this prevents relevant interpretation of the results and approaches from natural sciences in the social sciences, and vice versa (Fischer et al., 2011). Having an interdisciplinary team aligned to pragmatic claims would allow for a middle ground for teams to focus beyond the scope of their approaches and work towards achieving a shared research goal, rather than emphasizing paradigmatic differences. Therefore, successful interdisciplinary projects should place the goal of

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managing a complex issue above disciplinary traditions.

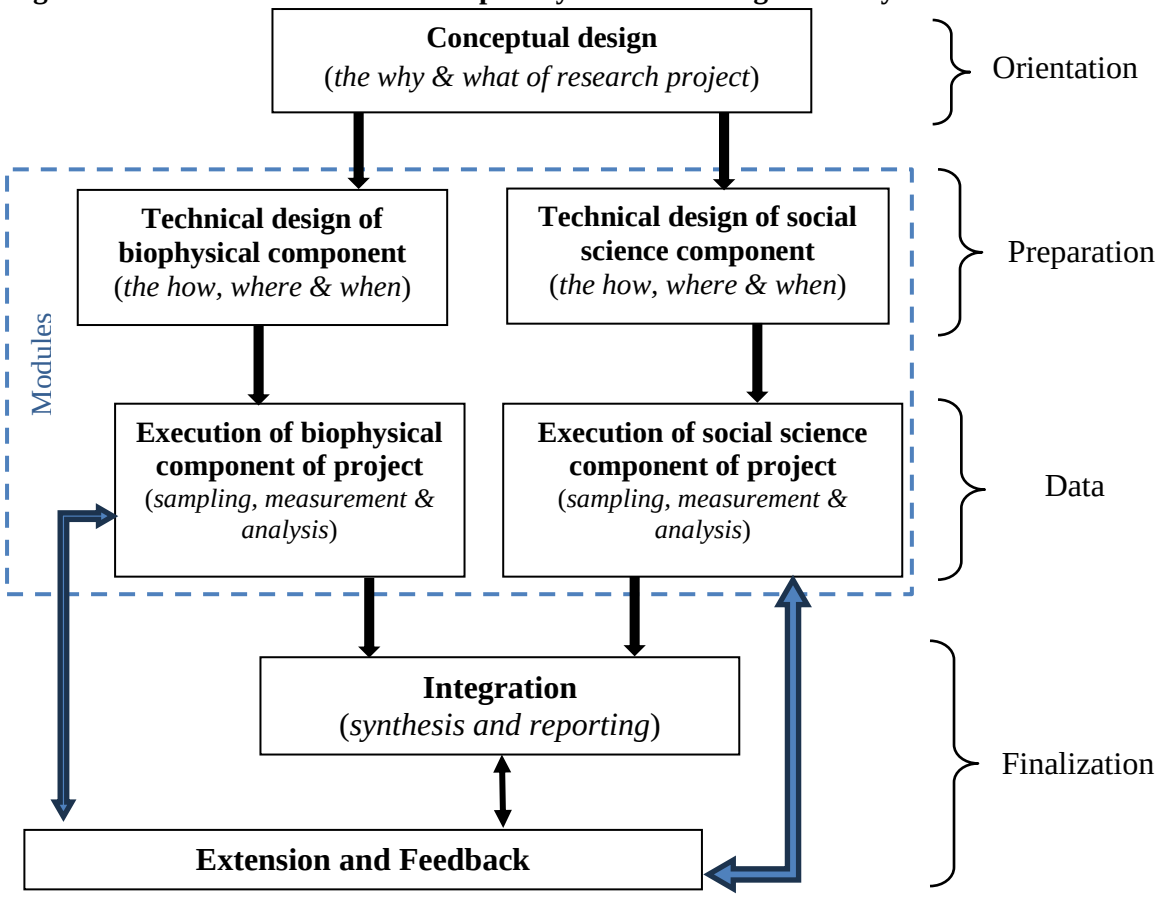
FRAMEWORK FOR INTERDISCIPLINARY RESEARCH IN AGROFORESTRY

The general interdisciplinary research framework developed by Tobi, & Kampen (2017), involves five major components: 1) conceptual design of the study, 2) technical design, 3) execution of work, 4) an interdisciplinary synthesis and 5) Integration. In addition to a few aspects from the University of Amsterdam's Institute for Interdisciplinary Studies (IIS) model (Rutting et al., 2016), we have suggested extension and feedback as an additional component to the framework, involving biophysical and socio-economic components especially in the context of developing countries (Figure 1). It is however important to note that the interdisciplinary research framework proposed here should not serve as a strict protocol as research processes differ in practice.

Conceptual Design

The conceptual design is the orientation stage of the interdisciplinary process (Rutting et al., 2016), during which the common goals required for interdisciplinary collaboration are ascertained (Fischer et al., 2011). This stage contains the 'why' and 'what' of the research. Through activities such as thinking, exchanging interdisciplinary knowledge, reading and discussing, key aspects including research objectives, theories and research questions are developed (Tobi, & Kampen, 2017). Where the project is being implemented by an interdisciplinary team, the teams are expected to come together during this stage to choose a suitable topic and identify the research problem, while ensuring that each relevant discipline is reflected in the choice and wording of the topic (Rutting et al., 2016). This requires good knowledge about relevant previous research (epistemology) from the different disciplines involved to ascertain new levels of reality (ontological questions) to investigate.

Figure 1: A Framework for Interdisciplinary Research in Agroforestry



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Technical Design

The technical design stage addresses the 'how', 'where' and 'when' of the research by identifying how measurements will proceed, and developing the sampling and analysis plans (Tobi, & Kampen, 2017). It is a preparation phase of an interdisciplinary research process involving thorough literature research from different disciplines (Rutting et al., 2016). At the technical stage, the teams or individuals undertaking the study are expected to be pragmatic to ensure that the study meets its practical demands about data collection and interpretation (Kumar, 2011). The role of the researcher is often a source of misunderstanding at this stage (Tobi, & Kampen, 2017). For example, in a biophysical experiment, the researcher is usually considered a neutral outsider while reading a standardized instrument (e.g. a sap flow metre measuring tree water use). In contrast, for a social scientist, the researcher and the interviewee are part of the measurement instrument, while the researcher is eliminated when an online questionnaire is used. It is also important to set the rules for deciding on data saturation. Such contrasts need to be harmonized at this preparation stage of an interdisciplinary research framework.

Execution of Project

This stage involves the actual field work to generate the required data for the project. The respective team members may do their disciplinary components of fieldwork (sampling, measurement and data analysis) on a modular basis (separately). For each interdisciplinary component, the researchers are expected to have a criterion for detecting data saturation and how to analyse the collected data (Rutting et al., 2016), following all the necessary scientific data quality and ethical considerations (Tobi, & Kampen, 2017). Paying attention to data quality and ethical considerations, researchers can appreciate each disciplinary concern for good quality research and recognize certain commonalities. Ethical issues generally run through all the components of the interdisciplinary research framework.

Integration

This involves synthesis of the information collected from the different disciplines and reporting the outputs. At this stage, the modules need to be brought together and these may rely on quantitative, qualitative or mixed methods approaches (Tobi, & Kampen, 2017) to integrate results and insights related to the research goal. Integration of information may be convergent (done parallel and integrated after completion), sequential (done after one another and the first modules inform the latter ones) or embedded, where modules depend on one another for data collection and analysis, and synthesis may be planned both during and after completion of the embedded modules (Creswell, 2018).

Extension and Feedback

Although Tobi, & Kampen (2017) did not include extension and feedback in their interdisciplinary framework, these are important in generating information essential for informing policy decisions relating to agroforestry. It has been argued that interdisciplinarity shouldn't only involve individual disciplinary specialists working together, but also allowing others' perspectives and methods to influence their understanding of problems (Sillitoe, 2004). This can be effectively achieved through extension and feedback mechanisms. However, there could be arguments that including extension and feedback would make the framework transdisciplinary rather than interdisciplinary, because it involves non-academic collaborators such as farmers. We argue that for interdisciplinary research in agroforestry to be successful, there must be a transdisciplinary aspect integrated into the research framework.

Feedback has been regarded as a fundamental bridging concept for advancing transdisciplinary sustainability research (Blythe et al., 2017). We therefore contend that interdisciplinary research in agroforestry should not end at synthesizing and reporting project outputs. It should also allow others' (usually non-academic collaborators e.g. farmers) perspectives to better understand the problem and generate more conclusive and impactful knowledge from the study. Engaging

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non-academic collaborators would also render the project socially relevant (Lowe, & Phillipson, 2006) while bridging science and development in the long term (Callo-Concha et al., 2017).

BARRIERS TO IMPLEMENTATION OF IDR IN AGROFORESTRY RESEARCH

We characterise the barriers in terms of time and effort requirements, human resource factors, and institutional and policy-related barriers.

Time and effort requirements: A key challenge in interdisciplinary work is to develop expertise in more than one area. It requires investment of a significant amount of time in building collaborative relationships and developing a shared language and a common perspective from disparate viewpoints (Bromham et al., 2016). IDR would therefore require more time and resources than monodisciplinary research (Davé et al., 2016) and funders who wish to support IDR have to consider how the additional resource requirements could be fulfilled. Interdisciplinary researchers reportedly work under considerably more stress than their disciplinary counterparts, especially in terms of time management, anxiety and inadequate interdisciplinary literature (NationalAcademies, 2005; Spanner, 2001). A researcher undertaking an interdisciplinary study would require additional training in a new field which may reduce their apparent productivity relative to that of a scholar who focuses on a single discipline.

Human resource factors: Most of the challenges faced by interdisciplinary research teams result from differences in training and scientific culture (Tobi, & Kampen, 2017). Researchers in one discipline often have a strained relationship with a researcher from another discipline (Cox, 2015), much to the detriment of the farmer, the end-user of the research data. Interdisciplinary teams are often put together by proximity and convenience rather than expertise and need (Butler, 2011). A shared understanding of how best to develop effective interdisciplinary researchers (particularly at early career stages) is lacking (Kelly et al., 2019), as specialized scientists tend to lack knowledge about other domains (Cox, 2015; Fischer et al., 2011). Learning something new, especially outside of one's major discipline, is disempowering and can create anxiety among interdisciplinary research teams (Butler, 2011; Davé et al., 2016). Building bridges between disciplines goes beyond just putting together an interdisciplinary team and charging them with solving a problem (Lele, & Norgaard, 2005). For interdisciplinarity to work well, cross-fertilization and cooperation are paramount.

Institutional and policy-related challenges: Existing institutional structures and practices to support interdisciplinary research are still developing (German et al., 2010; Kelly et al., 2019). However, effective solutions demand that we transcend institutional boundaries (Farley et al., 2010). It has been argued that disciplines lose meaning outside of academic institutions and that interdisciplinarity in real-world problems should be taken into account (Liu et al., 2010). Funding agencies play a key role in shaping interdisciplinary research (German et al., 2010; Lyall et al., 2013), with both positive influences, such as dedicated programmes for interdisciplinary projects, and negative impacts, as perceived biases can discourage submission of interdisciplinary proposals to open funding calls.

Interdisciplinary research is often encouraged at the policy level but poorly rewarded by funding instruments (Woelert, & Millar, 2013). There have been reports that many interdisciplinary research proposals face dismissal because they are scrutinized by academics who are discipline-based (Bromham et al., 2016; National Academies, 2005) and have difficulty understanding or seeing the merit of interdisciplinary research (Butler, 2011). Policy-makers need to recognize the benefits of a broader range of expertise in decision-making and incorporate social science into policy to complement the more established sources of natural science advice related to the agricultural sector. Collaboration with the social sciences can bring different perspectives and methodologies to help reframe agricultural problems and reveal multiple or disputed understandings and thus

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expose diverse possibilities and alternative meanings.

Opportunities for Implementation of IDR in Agroforestry

There has been a general longstanding call for interdisciplinary research between the social and the natural sciences to manage complex societal issues (Fischer et al., 2011; German et al., 2010), regardless of the many barriers that remain. Opportunities for collaboration occur when researchers are willing to adapt, with a strong interpersonal focus and interest in engaging in discussions with others while looking to broaden their horizons and step outside their field (Kelly et al., 2019). We propose that the sustainability of agroforestry research and development can only be achieved by ensuring that disciplinary experts have an interdisciplinary experience. We document two opportunities that can expose disciplinary experts to interdisciplinary experiences to foster sustainable agroforestry research and development.

Increasing Demand for Interdisciplinary Teams

The complex problems society is currently facing (e.g. global food insecurity, climate change) demand innovative solutions that combine knowledge from different scientific disciplines (National Academies, 2005). This is mainly because research carried out by interdisciplinary teams contributes to bridging multiple disciplinary concepts, theories and methods to solve problems that a single discipline cannot solve (Perez-Vazquez, & Ruiz-Rosado, 2005). Since agroforestry is conceived as a system formed by different elements (including institutions, society, and biotic and abiotic resources), IDR can contribute to a better understanding of the complex problems of agroforestry. There have been calls for increased support for interdisciplinary research in agroforestry, agriculture and life sciences in higher education (Miller, 2016; Spelt et al., 2010). Indeed, to achieve the interaction among different dimensions (e.g. social and biophysical) and its goals, interdisciplinary research has been considered the right approach (Perez-Vazquez, & Ruiz-Rosado, 2005).

The Potential of IDR to Address Global Agricultural Technology Adoption Barriers

Global agriculture demands increased food production to meet the projected global population by the year 2050 to feed the estimated 9 billion world human population (Miller, 2016; Ray et al., 2013). At the same time, available land is not increasing and agricultural production must be intensified on the available land while reducing environmental impacts (Miller, 2016). Addressing these global challenges requires the adoption of innovative agricultural interventions, especially by smallholder farmers (under 2 ha of land) that produce 28-31% of global food production (Ricciardi et al., 2018). We anticipate that the use of collaborative approaches such as interdisciplinary and transdisciplinary approaches in agroforestry research and development will be central to addressing global food security challenges. These approaches have been reported to be socially engaging (Lowe, & Phillipson, 2006) while facilitating the bridging of science and development in the long term.

CONCLUSION

We recommend that IDR in agroforestry be conducted within the pragmatic paradigm as a middle ground between positivism and qualitative-orientated paradigms. We promote a pluralistic approach around the concept of *'what works'* such that the focus of the research is on applications of techniques to solve a problem. We suggest an interdisciplinary research framework in agroforestry that involves six major components: 1) conceptual design of the study, 2) technical design, 3) execution of work, 4) an interdisciplinary synthesis, 5) Integration and 6) extension and feedback. From the reviewed literature, there is evidence of an ever-increasing demand for interdisciplinary teams to solve complex global challenges. We anticipate that the use of IDR will be central to addressing global food security challenges by bridging science and development. The current and future global complex agricultural sustainability challenges

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may require disciplinary experts with interdisciplinary experience. We believe that interdisciplinary research in agroforestry must increasingly become the standard rather than the exception because the approaches needed and the implications of agroforestry research are by their very nature interdisciplinary. While IDR should not be incentivised at the expense of good quality monodisciplinary agroforestry research, we anticipate that IDR can contribute to a better understanding of the complex problems of agroforestry, while increasing the policy relevance and the impact of research in developing countries.

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