





TRANSDISCIPLINARY INNOVATION IN IRRIGATED SMALLHOLDER AGRICULTURE IN AFRICA

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ABSTRACT

Boosting the productivity of smallholder farming systems continues to be a major need in Africa. Challenges relating to how to improve irrigation are multi-factor and multisectoral, and they involve a broad range of actors who must interact to reach decisions collectively. We provide a systematic reflection on findings from the research project EAU4Food, which adopted a trans-disciplinary approach to irrigation for food security research in five case studies in Ethiopia, Mali, Mozambique, South Africa and

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Tunisia. The EAU4Food experiences emphasize that actual innovation at irrigated smallholder farm level remains limited without sufficient improvement of the enabling environment and taking note of the wider political economy environment. Most project partners felt at the end of the project that the transdisciplinary approach has indeed enriched the research process by providing different and multiple insights from actors outside the academic field. Local capacity to facilitate transdisciplinary research and engagement with practitioners was developed and could support the continuation and scaling up of the approach. Future projects may benefit from a longer time frame to allow for deeper exchange of lessons learned among different stakeholders and a dedicated effort to analyse possible improvements of the enabling environment from the beginning of the research process. © 2020 The Authors. Irrigation and Drainage published by John Wiley & Sons Ltd on behalf of International Commission for Irrigation and Drainage

KEY WORDS: transdisciplinary approach; participatory innovation; smallholder farming, irrigation

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RÉSUMÉ

Le renforcement de la productivité des petites exploitations agricoles demeure une nécessité majeure en Afrique. Les problèmes relatifs à la façon d'améliorer l'irrigation sont multifactoriels et multisectoriels, impliquant un large éventail d'acteurs qui doivent interagir pour prendre des décisions collectives. Le projet de recherche EAU4Food a adopté une approche transdisciplinaire et participative dans cinq situations en Afrique du Sud, en Éthiopie, au Mali, au Mozambique et en Tunisie. Ces expériences montrent que l'innovation au niveau des exploitations agricoles ne peut se faire sans prendre en compte leur environnement et le cadre plus général des politiques agricoles. La plupart des partenaires du projet estiment que l'approche transdisciplinaire a effectivement enrichi le processus de recherche en diversifiant les points de vue. Les capacités locales de recherche transdisciplinaire ont été renforcées et cela permettra la poursuite et l'extension de cette approche. Il serait intéressant, pour les futurs projets, de disposer de plus de temps pour avoir des échanges d'expérience plus longs entre les différentes parties-prenantes, et de prendre en compte dès le départ l'environnement des exploitations pour y faciliter l'innovation. © 2020 The Authors. Irrigation and Drainage published by John Wiley & Sons Ltd on behalf of International Commission for Irrigation and Drainage

MOTS CLÉS: approche transdisciplinaire; innovation participative; petites exploitations agricoles; irrigation

INTRODUCTION

Food insecurity in Africa is a major concern that is expected to worsen because of population growth and climate change. In many African countries, the population size will double by 2050 and it is expected that the continent will reach 2.5 billion inhabitants by 2050.¹ Most of the population growth will be in the poorest countries of the sub-Saharan region that have been the hardest hit by hunger and malnutrition. Sub-Saharan Africa is also one of the most vulnerable to climate change and variability on the continent (Intergovernmental Panel on Climate Change (IPCC), 2014), which will have severe implications for food and water security.

Agriculture contributes on average 24% of the annual economic growth in Africa. Throughout the continent, smallholder farming is the dominant form of agricultural land use (World Bank, 2008). In semi-arid and arid regions of the continent, irrigation is considered indispensable to intensify food production.² Boosting the productivity of smallholder farming systems is an important pillar of rural development strategies for most African governments (Larson *et al.*, 2016).

Despite the call for increased irrigation to raise crop production, in 2006 African countries collectively irrigated only 5.4% (13.6 million ha) of their cultivated land, compared to the global average of around 20% and almost 40% in Asia (Food and Agriculture Organization of the United Nations (FAO), 2011). For decades, the international community has been searching for ways to raise farm productivity and improve livelihoods of smallholder African farmers. Despite significant investments, the past decades show only a slow-changing pattern (Collier and Dercon, 2014) and limited progress in developing market access and value chains (Devaux *et al.*, 2018). There is still widespread agreement on the need to increase productivity (Smith *et al.*, 2017) and to prioritize investment in distributed irrigation infrastructure (Burney *et al.*, 2013).

Re-examining development models for smallholder agriculture in Africa to include a broader vision beyond a narrow focus on smallholders is needed (Collier and Dercon, 2014). According to Collier and Dercon (2014), this broader vision requires inclusion of clear institutional frameworks, which could allow a more dynamic agriculture to develop. It has become clear that the problems surrounding irrigation

development are multi-factor and multisectoral, involving a broad range of actors who must interact to reach decisions collectively. It highlighted the need for new approaches that take into account the complexity of human–environmental systems and that accept the inherent uncertainties in collective decision-making and human behaviour—giving rise to multidisciplinary and transdisciplinary approaches to applied research in agriculture. Transdisciplinary approaches require investigators from different disciplines to work together to create new conceptual, theoretical, methodological and translational innovations that integrate discipline-specific approaches to address a common problem. Transdisciplinary approaches also include non-research stakeholders as equal partners (farmers or decision-makers in the private and public sectors) to ensure sustainability.

The research project EAU4Food³ adopted a transdisciplinary approach in five case studies in Ethiopia, Mozambique, South Africa, Mali and Tunisia, blending two main methods: on-farm trials of improved irrigation or crop management and multi-stakeholder platforms at different levels in order to identify problems and solution pathways that go beyond individual technical solutions.

The approach used in these case studies is very much in line with the concepts of sustainability science—a field that has matured over the past decade (Leemans, 2017) and that acknowledges the involvement of other epistemics to address uncertainties and the complexity of ill-defined problems (Spangenberg, 2011; Lang *et al.*, 2012; Scholz and Steiner, 2015a,c) and aims to create knowledge that is solution-oriented, socially robust and transferable to both the scientific and societal practice (Lang *et al.*, 2012). In this view, *transdisciplinarity* can be seen as a core concept of sustainability science and *is understood as a facilitated process of mutual learning between science and society that relates a targeted multidisciplinary or interdisciplinary research process and a multi-stakeholder discourse for developing socially robust orientations about a specific real-world issue* (Scholz and Steiner, 2015b).

There is an abundant literature on research into participatory irrigation management (e.g. Khadra *et al.*, 2017; Senanayake *et al.*, 2015). The majority of these research efforts focused on involving farmers in the actual management of irrigation systems, but not necessarily on involving them in shaping the research process itself. Additional research concentrated on improved involvement of farmers' communities in the knowledge exchange process, in order to value explicit and implicit knowledge equally (Hoffmann *et al.*, 2007), to involve a wider range of stakeholders (e.g. Ritzema *et al.*, 2008), and conceptualize co-innovation in the value chain (e.g. Meynard *et al.*, 2017).

Addressing problems of smallholder farmers in a transdisciplinary approach has already been applied, for example in the context of implementing the *primary innovation*

programme such as the Agricultural Innovation System in New Zealand (Botha *et al.*, 2014), developing smallholder farming systems with a focus on fertilizer use (Njoroge *et al.*, 2015), addressing water quality problems (Steelman *et al.*, 2015), or contributing to sustainable development (van Breda *et al.*, 2016).

However, before executing the project EAU4Food fewer experiences of implementing transdisciplinary approaches have been reported in the literature when it comes to the specific issue of innovation in irrigated agriculture for smallholder farms in Africa.

In this reflection paper we share insights and experiences gained during the implementation of the EAU4Food research project. Under this research, we systematically reflected on our insights in relation to six key principles of transdisciplinary research, which were derived from different review articles (Lang *et al.*, 2012; Miller *et al.*, 2014; Scholz and Steiner, 2015a; Spangenberg, 2011; Steelman *et al.*, 2015). These principles are: (i) engaging with the non-scientific community; (ii) establishing a coherent system definition and problem framing; (iii) analysing the system and developing solutions jointly; (iv) integrating results from different disciplines, classical and transdisciplinary approaches; (v) reintegrating knowledge into practice; and (vi) performing a periodical internal and external evaluation. Using this generic skeleton allows us to conclude on key elements that need to be considered in future transdisciplinary interventions to foster innovation in irrigated smallholder farming. The application is underpinned by evidence-based knowledge and insights from the six case studies mentioned above.

IMPLEMENTING PLATFORMS FOR A TRANSDISCIPLINARY APPROACH TO INNOVATION

EAU4Food adopted a transdisciplinary approach, putting farmers' problems, needs and aspirations at the centre of the research and decision-making process, and diffusing and encouraging the active exchange of knowledge with the wider stakeholder community. A key aspect of transdisciplinarity is the mutual learning between science and society to cope with the contextualization of complex, real-world problems (Scholz *et al.*, 2006).

The established multi-stakeholder platforms combined *communities of practice* (CoPs) (Wenger, 1998) at a local level following the Tadla approach (Dionnet *et al.*, 2008), and *learning and practice alliances* (LPAs) at regional or national levels that originate from the Research-inspired Policy and Practice Learning in Ethiopia and the Nile Region (RIPPLE) (Callow *et al.*, 2013). During the implementation of the project, the concept of integrating CoPs and LPAs was further advanced by researchers of the

Overseas Development Institute (ODI) and the Lien Social et Decision (LISODE) towards an operational approach (Mason *et al.*, 2011; Mtisi, 2011), (Tucker *et al.*, 2013) (Figure 1).

The focus of the CoP is to facilitate farmers’ innovations at the local level in order to ensure farmer-to-farmer learning, directly involve farmers in the research process (problem identification, data collection and interpretation of results) and direct farmer–researcher interaction.

Members of the CoP were mainly farmers from the selected case study sites, local practitioners such as extension service staff, and representatives of institutions responsible for the local operation and maintenance of irrigation systems.

The LPA concept supports the integration of local actors, researchers and policy-makers at different levels. The LPA brings together a range of stakeholders to exchange knowledge and generate innovations, share experiences, develop joint agendas for change and test new solutions to common problems. In this way, the LPA acts as a vehicle for joint research, learning, and supporting the implementation of innovations throughout the project. At a subnational level, it aims at providing guidance and expertise and to link practice to policy.

Based on RIPPLE’s experiences (Calow *et al.*, 2013), LPAs ideally consist of a wider range of high-level stakeholders and senior experts who can help bring about the necessary changes in the enabling environment that will allow innovation to take place. The composition of the LPA and CoP was decided based on consultation with local stakeholders and partners in the initial stage of the project, alongside an analysis of national and local political and social conditions.

The key advantage of integrating CoP and LPA includes, but is not limited to, facilitation of the exchange of ideas, knowledge and values: (i) between scientific disciplines, non-scientific knowledge and other perspectives; (ii) between research and practice; and (iii) across administrative hierarchies. The CoP–LPA combination enabled a move beyond academic disciplines altogether, seeking the integration and active participation of practitioners and decision-makers in the research process. In this way, the CoP–LPA contributes to the integration of perspectives regarding extra-scientific and societally relevant challenges (as e.g. postulated by Burger *et al.*, 2003). This could potentially develop into sound discourses and ultimately re-establish trust (Spangenberg, 2011) among scientists, practitioners and policy-makers.

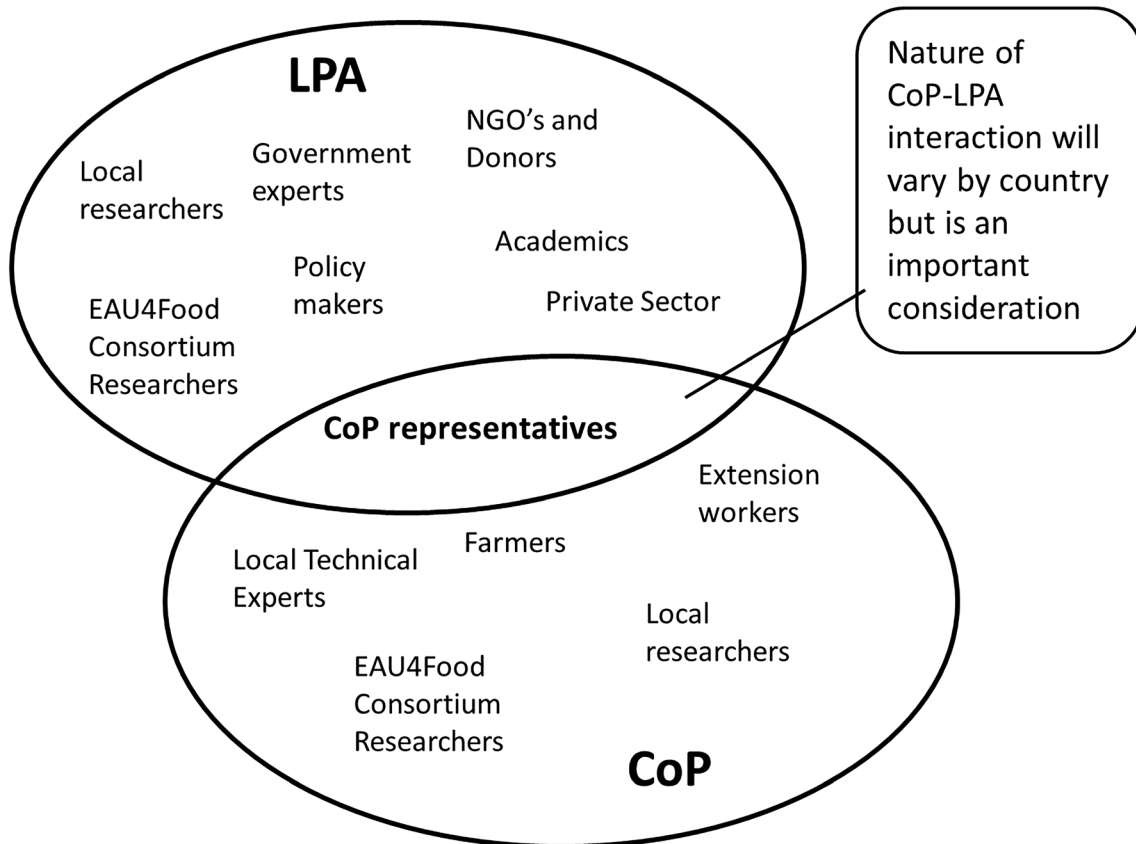


Figure 1. Integration of the LPA and CoP as central elements of the EAU4Food project

The implementation of the approach followed a sequence of phases: (i) problem framing and team-building; (ii) co-creation of solution-oriented transferable knowledge; and (iii) reintegration and application of created knowledge, as proposed by Lang *et al.* (2012) to develop an ideal-typical conceptual model of a transdisciplinary research process.

The coordination of the CoP–LPA process was organized by local action research teams which, for that purpose, also included researchers from ODI and LISODE. Following the logic of the transdisciplinary approach, the CoP initiated the identification of key problems and the related research priorities using two methods: First by *photo safari*—asking farmers to document the problems they face by taking photos with a camera provided, and also, where possible, document local innovations. Second, by the *problem tree*—whereby a group of farmers identifies a set of key problems (the stem) and then works backwards to identify the root causes (the root) and upwards to suggest solutions (the branches and leaves). The results were then presented to the LPA for comment and comparison with the problems identified by the higher-level stakeholder community. Subsequently, a research and experimentation strategy was developed and agreed with farmers at the CoP level, as well as by the LPA.

Where possible, farmers were involved in data collection and carrying out research and experimentation on their own land. Their views in relation to the criteria for the success of an experiment were considered alongside scientific criteria. The research results were presented within the LPA and CoP. The results of the case studies were also exchanged annually among members of the research community. Outreach and dissemination occurred through formal CoP and LPA meetings, individual farmer field days, as well as through traditional academic presentations conducted in-country and internationally. Bilateral discussions between local case-study coordinators and higher-level stakeholders provided means to develop shared ownership of the approach and to exchange findings on problems and possible solutions.

The entire process was accompanied by outcome mapping, which is based on the rapid outcome mapping (ROMA) approach (Michel *et al.*, 2013; Young and Mendizabal, 2009). Outcome mapping was initiated midway through the project when partnerships, actors and key markers of change could be identified. Mapping included the following stages: (i) defining the objectives; (ii) understanding the basic context; (iii) identifying the underlying theory of change; (iv) developing an action plan based on available resources; and (v) deciding upon progress markers, monitoring progress and adapting as necessary. Specific objectives for planned interventions and related methods to reach them were developed in the rather late phase of the project after setting up the LPA and CoP.

EAU4FOOD CASE STUDIES

The case studies presented in this issue (for overview see Table I, Figure 2) were selected at the beginning of the research process to reflect different irrigation and farming systems, biophysical and socio-economic contexts, political settings, and cultural and linguistic context. They represent regional differences, but also similarities of smallholder irrigation systems in Africa. The cases represent three different types of irrigation systems: firstly, irrigation schemes supplied by river water (Mozambique, Mali); secondly, dam-supplied schemes (Ethiopia, Tunisia); and thirdly, individual farm irrigation systems with a water supply from boreholes or river abstraction (South Africa).

Each case characterizes a situation where smallholder farmers are dependent on access to irrigation water due to climatic conditions and face institutional barriers to innovation in irrigated agriculture. In all cases, the farmers are required to operate within the constraints of available land, access to water and prevailing conditions of the political economy.

Specific context analyses, problem settings, research approaches and results are elaborated in detail in the different papers of this special issue. The main objective of the current paper is to provide a synthesis of the benefits, limitations and future directions of implementing transdisciplinary research for sustainable development in irrigation.

Gumselassa irrigation scheme—Ethiopia

The Gumselassa irrigation scheme is situated in the semi-arid Tigray region, 25 km south of the region's capital, Mekelle. The mean annual rainfall is estimated at 513 mm yr⁻¹. The irrigation water is supplied from a reservoir, with a storage capacity of 1.9 million m³ through an open channel system. Currently, only 60 ha of the originally planned 110 ha are irrigated (Fissahaye *et al.*, 2017). Individual farmers are farming parcels of 0.2 ha, with maize and barley as the dominant crops.

The management of the irrigation scheme is primarily governed by a water user association (WUA) whose members consist of local farmers. Each year, the WUA holds an annual general assembly, during which key issues related to water allocation, conflict management, operation and maintenance of the irrigation system are discussed, and these discussions often resulted in new legislation called a *serit* (equivalent to a local by-law). The elected irrigation leader, the Abo-Mai, is responsible for operating the main canal gate, managing the distribution of water, supervising conflict mediation and issuing penalties. Originally, the Gumselassa irrigation area was divided into irrigation units. These units disappeared, and individual farmers are now

required to request water from the Abo-Mai, weakening the control of the WUA (Fissahaye *et al.*, 2017) over the use of water resources for their plots. A government-appointed district-level expert also has an advisory role within the general assembly. A recent evaluation of how government influences self-governing institutions to manage irrigation schemes showed that well-meaning government interventions often fall short of their objectives. Governments provide modern infrastructure, institutions and agricultural inputs, but these are often less tailored to local conditions and highlight the need for incorporating farmers' perspectives into planning and performance assessments (Oates *et al.*, 2019).

The EAU4Food intervention provided a means for farmers and government officials to collectively discuss issues surrounding the Gumselassa irrigation scheme. During the intervention, a plethora of challenges and a wide range of research priorities were identified, including joint research to improve soil fertility, agricultural practice, irrigation management and pest control. The key problems specified by the farmer community are: dam siltation, damaged canal infrastructure and in particular the broken second main gate at the dam outlet. However, these issues remain outside the farmers' influence and the scope of the EAU4Food research project. Nevertheless, these problems were raised at LPA meetings and brought to the attention of relevant government decision-makers. Researchers, farmers and government decision-makers alike also identified that operational structures should be developed to facilitate the involvement of farmers in the maintenance of local canal systems and guarantee government commitment to repair and maintain irrigation canals and dam gates.

KO2 irrigation scheme—Mali

The Niger KO2 irrigation scheme is located in the Niger inner delta, in a semi-arid area with mean annual rainfall of 433 mm yr⁻¹). The scheme consists of 13 tertiary canals, about 300 ha irrigated land for 195 farms and is located downstream of Niono. Water is provided through open channels from the Niger River. The Office du Niger is responsible for the maintenance of the canal infrastructure covering both the irrigation and drainage systems. Currently, agricultural productivity is hampered by organizational issues and difficulties in coordinating agricultural water management.

During the CoP, farmers mentioned a variety of problems at the farm level, as well as at the level of secondary and tertiary canals, largely related to issues of soil fertility management, maintenance of canals and a lack of communication between the staff at the Office du Niger and farmers.

The most important threat to the successful implementation of the CoP-LPA approach in Mali was the political

and security crisis in 2012, which forced the local researchers from Institut d'Economie Rurale, Mali (IER) to implement the entire transdisciplinary approach without the local presence of international research partners.

Chokwe irrigation scheme—Mozambique

The Chokwe irrigation scheme was the first in Mozambique and was built in the 1950s. It is located in the inundation plain of the Limpopo River basin, receiving an average rainfall of 630 mm yr⁻¹, and is particularly vulnerable due to the influence of the palaeodelta in the flood dynamics. The scheme is the largest in the country with a total area of 30 000 ha; large commercial farmers occupy 64% of the area, and smallholder farmers make up the rest, usually farming less than 2 ha on average (Ducrot *et al.*, 2019). During the 2012/2013 season, only a small fraction (6849 ha) was irrigated for agricultural production due to salinization and poor infrastructure exacerbated by recurrent flooding. After several transformations (Veldwisch, 2015), Hidráulica de Chókwè Empresa Pública (HICEP) is now responsible for maintaining the primary water distribution infrastructure. The maintenance of the secondary to quaternary infrastructure for both irrigation and drainage is the responsibility of the farmers that make up the 36 WUAs. The capacity of both the WUAs and HICEP to organize and follow through with necessary maintenance is weakened mainly by institutional barriers, lack of coordination and communication, all of which are exacerbated by recurrent flooding. During the 2013 flood, the scheme, the city of Chokwe and neighbouring districts were all inundated. Using a transdisciplinary approach which included WUAs and HICEP, the impact of the 2013 flood event on the functioning of the scheme was analysed collectively. The intervention provided an opportunity for all actors involved to rethink their responsibilities and communication strategies in order to recover from the crisis. The approach focused on the relaunch of agricultural activities after the flood.

Farmers also indicated their desire to lower production costs. Together with the farmer association '21 de Maio', experiments were conducted to produce compost out of the local crop residues and, thereby, reduce the need and associated costs of mineral fertilizers.

Greater Giyani Municipality—South Africa

The South African case study was conducted on two individual women's cooperative farms located in the Greater Giyani Municipality area (receiving rainfall 500–600 mm yr⁻¹), which is part of the lower Letaba River basin in Limpopo Province. Irrigation is practised by pumping water from the river (Zava farm) or from groundwater (Mzilela). Maize and vegetables are the major crops cultivated in the

area. Farmers were not formally part of a WUA and there is no operational catchment management agency (CMA). The Giyani area was earmarked for development by the national Comprehensive Rural Development Programme (CRDP) (2009) and the selected women's cooperative is supported through government extension services (local office of the Department for Agriculture and Rural Development). The farmers listed the following main problems in this case study: (i) a lack of equipment; (ii) inadequate farm management; and (iii) limited access to markets. Of all the cases within the EAU4Food project, that in Giyani was characterized by the greatest remoteness in relation to where in-country researchers are situated (Stellenbosch and Pretoria). Therefore, it was originally planned to involve the local department of agriculture (LDA) as closely as possible in the facilitation of the experiments and the co-organization of the CoP and LPA, targeting continuation after the lifetime of the project. Due to a number of technical and organizational problems, the experiments only continued in one out of the four farms. The experiments were finally mainly carried out by the researchers. Despite the intensive support of facilitating the LPAs and CoP by the project researchers, a strong widespread uptake of the introduced technologies, continuation of the LPAs/CoP through the LDA and promotion of the proposed approach at province, district and local level could not be achieved, as there were too many intrinsic barriers to be overcome (mandate and resources at LDA level, too advanced an irrigation practice for uptake without further support), limited resources for the research project to maintain a sufficiently long follow-up). Nevertheless, the intensive interaction and communication led to a better understanding of underlying barriers, a principal recognition of the value of the approach, and some appetite in the farming community to follow the example of the demo farm.

Brahmi irrigation scheme and Abida—Tunisia

The Brahmi irrigation scheme is located near Jendouba and is supplied by the Bou Heurtma dam. This semi-arid region receives mean annual rainfall of about 560 mm yr⁻¹. The scheme was established in 1987 and covers 5000 ha. The water is delivered through a pressurized distribution system. The cropping pattern previously followed a four-course rotation of sugar beet/cereals/forage and vegetable production. Problems with scheme management, increases in production costs, stagnation of market prices and closing of the milk and sugar-beet factories significantly affected agricultural production in this area. The crop rotation system has now shifted to a 2-year cycle and to monoculture cereal production in some parts of the scheme.

The regional state office for rural development, the Commissariat Régional au Développement Agricole

(CRDA), is responsible for operating the primary and secondary level water supply. Six WUAs called *groupements de développement agricole* (GDAs), are in charge of operation and maintenance at tertiary level.

The age of the system and lack of maintenance are major threats to securing water supply at all levels. Tensions due to sharing of responsibilities between GDAs and CRDA lead to frequent misunderstanding and conflicts among individual farmers, GDAs and CRDA.

The key issues identified by the farmers were: managerial challenges (including financial issues), system maintenance and the demand for a working extension service system. Furthermore, there is a need for farmer organizations to connect to agro-industries so that they can benefit from extended value chains. In addition, there are problems with obtaining high-quality seeds and drainage needs to be improved, in particular during the winter months.

Table I. Comparative overview on key aspects from implementing the transdisciplinary approach within 5 Case study regions. Figure 2

ENGAGING WITH AN EXTENDED, NON-SCIENTIFIC PEER COMMUNITY

A diverse set of actors and stakeholders from the non-scientific community were actively engaged in the EAU4Food case studies to co-develop research activities. This fulfilled a key principle in transdisciplinary research and constituted, to some extent, a paradigm shift in advancing smallholder irrigation.

The EAU4Food project was able to take a few important steps towards resolving important issues surrounding irrigation at these sites. However, much more needs to be done in order to fully implement a transdisciplinary process, as well as reaching a significant improvement in irrigated production. This should not be surprising, given the complexity of each site and the fact that the transdisciplinary approach was new for most of the researchers from both Europe and Africa, who, with a few exceptions, predominantly have a technical background. Achieving the key objectives of a transdisciplinary approach requires an extended commitment on the part of all stakeholders and requires time to be fully integrated. Participatory processes are influenced by the context and strategies of the participants. It remains a challenge to manage the diversity of expectations and to safeguard a continuity of participation (Hanafi *et al.*, 2019; Musvoto *et al.*, 2015).

Dolinska *et al.* (2019) highlighted the readiness, in particular of researchers, to participate in the transdisciplinary process. Important learning has taken place for all participatory researchers in the EAU4Food project.

Table 1. Comparative overview on key aspects from implementing the transdisciplinary approach within 5 Caste study regions (synthesis from Ludi and Oates, 2015)

Study site	Gumsalassa Irrigation Scheme	KO2	Chokwè Irrigation Scheme	Mzilela Farm	El-Brahmi
Country	Ethiopia	Mali	Mozambique	South Africa	Tunisia
Local case study coordination	Mekelle University	Institute d'Economie Rurale	University Eduardo Modlane	CSIR and Stellenbosch University	INGREF
Lead LPA/CoPP development	ODI	LISODE	ODI	ODI	LISODE
Contributing research partners abroad	CIRAD, IWMI, Wageningen Research, CSIR, LISODE	IRSTEA, CIRAD	CIRAD, CEBAS, LISODE	Wageningen Research, IWMI	IRSTEA, CIRAD
CoP participants	Farmers, extension agents, researchers	Farmers, researchers, Office du Niger, OERTs – managing tertiary network, NGOs	National government, regional/district government, scheme managers, farmer reps., researchers, private sector	Gov. reps. (province, district municipality, local municipality level), private sector, farmer reps, researchers	Researchers, extension service of CRDA, WUA reps., farmers, consultant from sugar complex
LPA participants	Regional gov. experts, NGOs, farmer reps., district offices, extension agents, researchers	Farmers, researchers, OERTs – managing tertiary network, Ministry of Agriculture, farmers corporations	Farmers, scheme managers and researchers	Farmers, extension agents, researchers	Farmers, Office of Livestock & Pasture (OEP), researchers, CRDA, WUA reps., milk factory, tomato factory, sugar factory, milk collectors, land agency
Problems identified	Inequity in water sharing; Poor irrigation schedule; Soil salinization; Damaged infrastructure	Lack of canal maintenance; Irrigation scheduling; Seeding techniques	Infrastructure damaged after 2013 Flood	Lack to adequate irrigation equipment (access to water); Farm management; Marketing	Water management and drainage in the lower parts; Lack of maintenance of collective hydraulic equipment; Lack of professional farmers' organizations to face agro-industries and other value chains actors; Poor crop rotations
Key steps performed	Participatory problem identification (CoP and LPA, incl. farmer photo safari); Farmers directly involved in experiments on their plots (incl. collecting data) and employed to collect scheme-level	Council of research users – defining local needs and validating with stakeholders; Participatory problem identification (incl. photo safari); Farmers directly involved in experiments on their plots (incl. collecting data) and employed to collect scheme-level	Participatory problem identification (CoP and LPA); Farmers directly involved in experiments on their plots and employed to collect scheme-level data; Role playing games (RPGs), focus	Participatory problem and solution identification (CoP and LPA) incl. photo safari on one cooperative farm; Farmers at experimental sites involved in collecting data and farming tasks	Participatory problem identification and discussion (CoP and LPA, incl. photo safari); Farm-level research on priority topics; Selected farmer leaders each supervise 10 other farmers e.g.

(Continues)

Table I. (Continued)

Study site	Gumsalassa Irrigation Scheme	KO2	Chokwè Irrigation Scheme	Mzilela Farm	El-Brahmi
	<p>data; Collaborative interpretation of results (field days, CoP, LPAs); New committee (district offices, WUA, MU) for action-research on drainage and salinisation</p> <p>Good uptake of certain innovations incl. in another irrigation site and rain-fed plots (e.g. using manure and dam silt to improve soil fertility); Others require more training (e.g. how to prepare botanical pesticides, application rates); water scarcity a big challenge in 2015 delays to research due to floods</p>	<p>plots (incl. data collection); Collaborative interpretation of results (field days, final CoP); farmers explaining research to other farmers</p> <p>Evidence of uptake (e.g. 3 farmers have changed their rice planting practices); Farmers not directly involved in project are also implementing innovations</p>	<p>groups and interviews; Participatory workshops; New, institutionalised stakeholders dialogue platform led by INIR</p> <p>Delays to research due to floods</p>	<p>on experimental plots; Collaborative interpretation of results; Agreement with SPAR supermarket in Giyani to buy produce from experiments</p> <p>Good uptake at farm level including (anecdotally) among neighbouring farms; Clear demonstration of yield and income benefits of more efficient and scientific farming practices</p>	<p>conveying message from researcher of when to irrigate ; Discussion/ interpretation of research results</p> <p>Irrigation management -> yield increases; Farmers requested to repeat operations in 2014/15 season; Success of farmer leader model to disseminate timely information; Simulation for diary productivity -> at least 1 farmer is implementing new farming system tested in game, interest in using game as an extension tool</p> <p>Political unrest/change and decentralisation made it difficult to have influence at regional level; Project played a role in re-connecting stakeholders and moving towards constructive discussion of problems</p>
Uptake of Innovation and impact by farmers (time to short to assess impact due to limited project duration)	<p>Difficulties reaching high levels of influence (regional gov.); Site specificity of research, time and budget constraints, competing priorities; BUT signs of uptake by extension agents (e.g. inclusion of new innovations in farmer trainings), and district offices (e.g. plans to extend drainage innovations to other schemes); interest expressed by regional stakeholder to scale-up to similar sites</p>	<p>Conflict weakened potential of LPA platform; Difficulties engaging Office du Niger in activities beyond CoP meetings (although interest expressed in disseminating work on local network management)</p>	<p>INIR planned to replicate LPA platform in other locations; scheme managers are developing plan with farmers for participatory infrastructure maintenance</p>	<p>Key challenge of personnel – investment in one core relationship at policy level (Provincial) but individual has now left</p>	
Uptake of Innovation and impact by government					

One aspect that demands further attention in future projects is the vicinity/remoteness of study sites from where researchers or other project implementers are located. Implementing a transdisciplinary approach requires experienced facilitation throughout the entire process. There is also a need to manage emerging demands, local interests and involvement of stakeholders across all relevant levels within the given political economy.

The experience of the EAU4Food project highlights the advantage of having local research institutions close to the study sites to develop and build capacities to engage in a transdisciplinary process, as was the case in Ethiopia and Mali. The greatest distance between the local research community and the study site was in South Africa. However, in Mozambique and Tunisia local researchers also had to make a considerable effort to reach the study sites and to engage with the farmers and the wider stakeholder community.

Overall, there is a great need to advance researchers' capacities for engaging in a transdisciplinary approach and to contribute to its facilitation. The involvement of expertise remains a challenge in advancing transdisciplinary approaches. Both the ODI and LISODE made enormous efforts to facilitate the local transdisciplinary process, as well as to convince sceptical researchers about the usefulness of a transdisciplinary approach and increase the capacity of the entire research consortium. Arranging the long-term presence of researchers is essential in order to gain an in-depth understanding of the framework conditions under which innovations can take place. This is reflected in the outcome of the effort of Centre de coopération internationale en recherche Agronomique pour le développement (CIRAD) to participate in the Mozambique case study (Ducrot *et al.*, 2018, 2019).

How to build sufficient local facilitation capacity, enable researchers to rethink their role (Dolinska *et al.*, 2019) and organize the involvement of technical expertise effectively, remain key questions for sustainability science.

Maintaining continuous local stakeholder participation in CoPs and LPAs was a challenge in all five countries. Busy schedules, competing projects and high staff turnover made it difficult for government and staff to sustain involvement at the individual level. Where smallholder farms are scattered and widespread, as was the case in South Africa, high costs of travelling made it difficult for researchers and staff to visit the farms or to allow farmers to attend meetings.

According to Hanafi *et al.* (2019), participants in the CoP group discussions can also quickly become disappointed when it is not clear to them that the meetings will effectively contribute to immediate solutions. At the same time, farmer initiative to engage in the transdisciplinary process is clearly affected by the attendance of high-level decision-makers at the LPA and the resultant opportunity for farmers to emphasize relevant problems and receive some sort of recognition.

Overall, deciding which groups and stakeholders should be included in meetings is an important consideration for the transdisciplinary process to be effective.

A comparative analysis of case studies from Ethiopia, Mozambique and Tunisia revealed that working on the already existing groups and building on prevalent formal dialogue groups is very helpful to create learning communities (Dolinska *et al.*, 2019).

COHERENT SYSTEM DEFINITION AND PROBLEM FRAMING

Joint problem identification and systems analyses are essential to create a basis for the development of solution-oriented and transferable knowledge (Lang *et al.*, 2012). This should be as open as possible in order to allow a maximum number of actors to participate and air their priorities and to enable ownership of the results. Focusing on a distinct main issue can also stimulate the motivation of participants to engage more fully in the process (Hanafi *et al.*, 2019). Attention should be paid to maintain good continuity in participation and keep as far as possible the same stakeholders within the process. Obtaining a thorough inventory of key problems to be addressed is, therefore, indispensable. Starting with the photo safari and problem tree analyses, ranking and reflecting on the problems within the CoP and the LPA were positively experienced and confirmed the practicality and effectiveness of these methods. However, all of the case studies showed that reaching a coherent system definition and problem framing is not trivial and depends on two main factors. First, the preselection of a specific problem to be addressed (in this case focusing on improving irrigated smallholder agriculture) is a key factor. In our case the preselection was done at the proposal stage of the project. Second, the choice of stakeholders involved in the definition process strongly influences coherent system definition and problem framing.

In retrospect, more effort should have been made to involve stakeholders from the LPA during the baseline report development, which could have led to a better shared understanding of the context and perceptions of the enabling environment in which the innovations needed to take place.

Additionally, bias in the specification of priority issues can influence problem framing as well. From the beginning, the case studies focused on smallholder irrigation and due to the composition of the project consortium, a technical bias was apparent. Within the problem framing, field-scale topics emerged strongly as dominant issues, while many of the underlying drivers, such as lack of funding for maintenance of infrastructure, weak value chains or inefficient coordination between different line ministries, were not identified as key issues the research could address. If a wider starting point

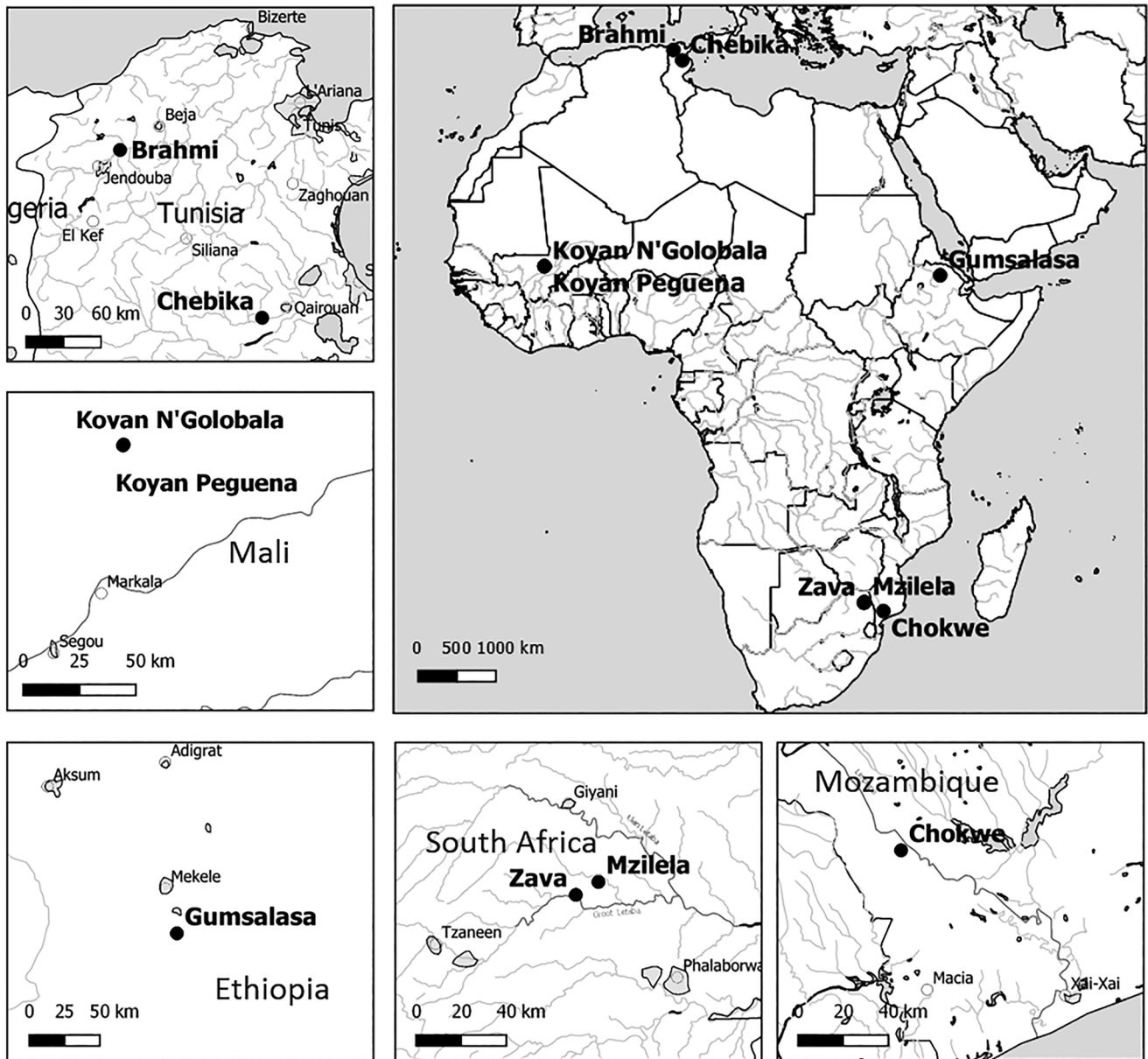


Figure 2. Locations of the case-study sites, providing an overview at continental scale (top left) and vicinity to nearby towns per country (small sections surrounding)

had been chosen, such as achieving food security, different actors would (most likely) have been involved, which could have led to a different system definition, problem framing, selection of research priorities and scales. Previous research emphasizes the influence of dominant individuals and the potential influence on problem definition by individual interviewees over a collective problem prioritization (Hanafi *et al.*, 2019). In our project, the combination of CoP and LPA was helpful to identify biased perceptions (if any) and could determine whether or not dominant individuals were exerting strong influence on the process.

The case studies also revealed that prioritized solutions that were identified to address problems were often outside the farmers' sphere of influence; for example, the solutions were and clearly related to the absence of an enabling environment that favours self organized innovation. In some cases, problem framing was more related to issues that should be addressed by traditional government interventions or development projects. Examples include: the request for technical assistance and new infrastructure in Tunisia, South Africa and Ethiopia, the request for better education opportunities for extension service staff in South Africa or

expecting aid and financial compensation for the post-flood recovery in Mozambique. Such kinds of problem framing are often beyond the scope and capacity of a research project like EAU4Food.

Future research projects should take into account developing objectives and methods at an earlier stage in order to obtain progress markers and allow for refining research activities or stakeholder engagement strategies, which could further increase ownership of important and relevant research results.

JOINT SYSTEM ANALYSIS AND DEVELOPMENT OF SOLUTIONS

Farmers were involved in diverse types of experiments in each case study. By considering all case studies, a fairly comprehensive compilation of relevant elements for increasing the production in irrigated agriculture was investigated.

For example, testing seeds and seedlings was the topic in Mali (drum seeder with pre-germinated seeds) and South Africa (alternative tomato seedlings). Irrigation scheduling was a clear focus in the Ethiopian and South Africa cases. Improving soil fertility was targeted in South Africa (mulching, mineral fertilizer) and Mozambique (producing compost). Work on the Ethiopian case study elaborated the alternative production of pesticides, whereas viable weeding practices were tested in Mali. Experiments on a more strategic level, such as innovating crop rotations and enhancing dairy production, were the focus in Tunisia, while developing solutions for canal maintenance and/or the planning of maintenance was central in the Mali case study and in Mozambique.

An open transdisciplinary process led to different focal areas in the various experiments. The involvement of farmers in the planning of experimental work and in the execution of research activities varied considerably among the case studies. The variation was for different reasons, ranging from local circumstances, identified (priority) problems, external events such as floods and political crises, and the capacities of research teams to provide meaningful support in the innovation process. The involvement of farmers' communities was influenced by the composition of local research teams, their familiarity with transdisciplinary approaches and related perceptions as to what extent farmers' communities should actually become involved.

The involvement of farmers in defining problems and carrying out on-farm trials led to a very intensive and interactive participation of farmers in the research and experimentation activities in Ethiopia, Mali and Mozambique, as described by Dolinska *et al.* (2019), Habtu *et al.* (2019) Sánchez-Reparaz *et al.* (2019), Dicko *et al.* (2019) and Diawara *et al.* (2018).

In Mali, local knowledge of farmers was highlighted in a participatory process that used their own perception on the elaboration of irrigated rice yield (Diawara *et al.*, 2018); amongst others, farmers built yield determination diagrams that were surprisingly close to internationally famous scientists' writings such as Matsushima (1966) or Yoshida (1981). This indicates that it is not always knowledge that prevents farmers from applying best practice, but there is a need to adapt the practice to local constraints. Local knowledge was then used to conduct tests of alternative rice implementation techniques, comparing direct sowing and transplanting. Intensive group discussion on challenges and opportunities paved the way for a broader dissemination of a technical innovation (wet direct seeding using pre-germinated seed in paddy fields), which had been experimented with by only a few farmers until then.

A more indirect involvement of farmers took place in the South African case study. Here, the experiments took place on the property of the local women's cooperative and allowed a direct comparison of yields from crops grown by applying farmers' traditional production methods with those yields of advanced production methods that were performed by the local research team. Instead of carrying out physical experiments on farmlands, the case study in Tunisia was based on a role-play game that led to a very solid involvement (self-organization) by the local farmers' community (Dolinska *et al.*, 2019). This was also the case in the work dealing with maintenance in Mozambique (Ducrot *et al.*, 2018).

Involving stakeholders directly in experimentation, sampling and analysis requires significantly more effort than in a traditional research project. Yet the value of such involvement is demonstrated in the case of Gumselassa (Habu *et al.*, 2019), where joint elaboration and discussion of water balances with the farmers' community led to a shared insight that more water could be provided to the tail-end farmers—contributing to equitable water distribution.

All cases demonstrated the relevance of adapting the experimental work in such a way that farmers can assume a greater responsibility for the conceptualization and execution of the experiments. In this context, researchers who engage in a transdisciplinary approach must be open to less stringent or sophisticated experimental designs and allow sufficient time to plan and execute local experimentation with significant input from farmers.

Dolinska *et al.* (2019) showed that involving farmers in a real physical experiment demands considerable investment of farmers' time and labour. Only slight increases in productivity, either because less suitable experimental set-ups were chosen or because of external climatic factors, create a high risk of discouraging farmers from engaging in future transdisciplinary projects.

INTEGRATION OF RESULTS FROM DIFFERENT DISCIPLINES, CLASSICAL AND TRANSDISCIPLINARY APPROACHES

Lang *et al.* (2012) highlighted the need for integration across knowledge types, organizational structures, communication styles and technical aspects. The elaboration of solutions towards sustainable development should span different disciplines, scales and sectors.

In this regard, continuous and intensive cooperation is of critical importance. It takes time to develop a mutual understanding among stakeholders with different expertise and successfully achieve their expected contribution to the overall goal. Teams who already have an ongoing cooperation with farming communities have clear advantages in this regard. But even if the need for involving different expertise is jointly understood, limited financial resources and personal networks may hamper approaching partners from other sectors.

The integration of traditional disciplinary and transdisciplinary approaches is not an easy task. Within EAU4Food, local participatory experiments were accompanied by traditional disciplinary studies in order to provide further insight into specific problems. Relevant multidisciplinary efforts presented in this special issue are: (i) comparison of crop water productivity (Jovanovic *et al.*, 2019); (ii) examination of yield response in relation to different irrigation and fertilization scheduling scenarios under varying climatic conditions (Albasha *et al.*, 2019); (iii) simulation of better irrigation scheduling (Habtu *et al.*, 2019); (iv) advancing methods to extend life cycle analyses (LCAs) at territory scale (Pradeleix *et al.*, 2019). Despite the integrated CoP-LPA approach applied in EAU4Food, realizing an uptake of results from such in-depth studies in the design and execution of farmer-led experiments was not achieved within the 4-year project lifetime. Nevertheless, the conducted work was mainly used to raise awareness of a certain issue. Therefore, the joint achievement of results and their dissemination to local stakeholders contributes to important initial steps towards a pathway to successful co-development and co-implementation of a transdisciplinary approach. However, data acquired in a participatory working environment may only be available after selecting the priority issues and therefore often only at the end of the completed experiment/project.

Our results indicate that advancing methods in both agronomic and sustainability research can surely help to gain a better understanding of relevant processes in the future. However, if such developments are executed in parallel with the joint investigations of innovations in small-holder farming system productivity, results are often produced too late for timely inclusion in the stakeholder interaction process.

REINTEGRATION OF PRODUCED KNOWLEDGE

Reintegration of produced knowledge into practice and, hence, achieving actual innovation, is a central ambition of sustainability science. As highlighted by Dolinska *et al.* (2019), this is not the same as knowledge transfer from science to practice, but much more about getting a group of farmers to become a learning community.

One important assumption underlying the transdisciplinary approach is that the inclusion of stakeholders in the research process is critical for the uptake of innovation (Musvoto *et al.*, 2015). However, despite the co-development of particular strategies to improve irrigated agriculture, the actual reintegration of new practices within the EAU4Food case studies was relatively low.

There is a higher chance of reintegration of new knowledge in situations where farmers can realize innovation within their own financial and technical capacity and within their own sphere of influence. But even then, and despite obvious benefits, scepticism or simply habitualness can be factors that make it difficult to change the way farmers have been working for decades.

Furthermore, there are several barriers outside farmers' influence. Lack of access to information, funding and markets, improper maintenance of infrastructure and lacking institutional reforms require a systemic change of their own. To some extent, the private sector can help play a role in improving market access. However, governments have a major role to play in improving the enabling environment for innovation. In particular, in the context of irrigation management transfer, Oates *et al.* (2019) underlined the dilemma that while small-scale irrigation schemes should be self-governed, the introduction of new technologies and formalized institutions must receive state support. To support self-governance over the long term, ways should be sought to increase the ability to adapt public investment to diverse local contexts and build on existing institutions.

Sufficient time and continuity are key for a successful transition to take place. Innovations mature over a time horizon that generally exceeds the typical duration of a 4-year research project. Extension services could play a role in facilitating a continuous transdisciplinary process. However, the experience of the five case studies proved that many members of the staff were trained in the traditional *transfer of technology* (ToT) approach and engaging with farmers in a participatory manner was an alien concept for them, as it has been for researchers in irrigation for a long time as well. Extension officers are trained to teach farmers what to do and consequently do not consider their knowledge as of high value. Our research stresses that before extension services can play a leading part in the transdisciplinary approach, a different mindset and approach need to be established.

We also recognize that it is not only a matter of better differentiation of roles and responsibilities. Innovation can be severely hindered if there are tensions, distrust or different and conflicting expectations (Hanafi *et al.* (2019). The authors highlight the need for a productive interaction between researchers, farmers and government representatives.

Therefore, continuing the dialogue between farmers and the wider stakeholder community beyond the lifetime of an externally financed project can offer further opportunities to advance innovation in smallholder farm systems. Of all the case studies within the EAU4Food project, only the case of Mozambique provided signs of autonomous continuation. After several proto-LPA meetings, the Instituto Nacional de Irrigação (INIR) launched the official LPA in March 2014 to introduce the concept to different stakeholders as the Limpopo dialogue platform.

Finally, there is a need to adapt research and development instruments for enabling transdisciplinary approaches. Funds for reconstruction of infrastructure are not usually elements of research projects, neither do development projects easily create room for co-creation and in-depth experimentation. Creating and reintegrating knowledge should benefit from combined instruments, allowing a better combination of research and development programmes.

PERIODICAL INTERNAL AND EXTERNAL EVALUATION

Implementing a transdisciplinary approach provides an environment in which continuous learning and interaction occur. Outcome mapping and reflecting on an underlying theory of change should not be restricted to an evaluation of the technical impact achieved. Over time all participants (scientific and non-scientific) in the EAU4Food projects gained a greater interest in implementing the transdisciplinary approach (Ludi and Oates, 2015). A structured qualitative evaluation of the methods used by investigators—both the research and the innovation process—provides for a better understanding of the true barriers to innovation and ways to overcome them. Within the case studies presented here, transdisciplinary research was completely new to nearly all the participants.

A key here is to understand why the participants will have continued interest in the developed strategies or in further improving or implementing them. This insight calls for a creation of longer-term partnerships to stimulate joint discussion on evaluation and learning.

FUTURE PATHS FOR INNOVATING IRRIGATION WITH SMALLHOLDER FARMERS

The experience gained from EAU4Food and its five African case studies revealed the nature of the challenges faced by

smallholder farmers. Innovating smallholder irrigation is complex and includes relating to agro-technical, agronomic and socio-economic conditions and, above all, the political economy environment.

Successful transdisciplinary research that is able to address problems beyond the field level requires openness and relevant capacity from all involved stakeholders: on the one hand, decision-makers need to understand the evidence presented to them by researchers and act accordingly. On the other hand, farmers need to feel secure and valued to identify the problems they face and be listened to. Also researchers need to accept that there are other knowledge and value systems that are equally valid.

The objective of transdisciplinary research is to move beyond bridging divides in academia, to directly engage in the production and use of knowledge outside the academic world. The research is meant to co-create solutions that have emerged from collaboration with all the groups involved, with the ultimate goal of producing knowledge that can materialize meaningful change.

To contribute to meaningful change through a transdisciplinary process, scientists, researchers, in-country policy-makers and other stakeholders who have traditionally held dominant roles in decision-making, must reflect on their position and empower other stakeholders who traditionally had little or no voice. Acknowledging other knowledge and value systems as being equally valid is not an easy task, nor is it a simple feat to meaningfully contribute to a dialogue in an environment in which other groups, due to their perceived higher social standing, dominate the discussion.

Accepting that knowledge and value systems other than their own are equally valid is a challenge faced by all stakeholders in the transdisciplinary process.

In order to promote transdisciplinary research in future, additional ways should be found to reward the engagement of academia in farmer-led transdisciplinary processes. Measuring the true impact of a project is key and hence the commitment to participatory principles should be emphasized, which is not necessarily stimulated by measuring the scientific output by number of papers and h-index (Dolinska *et al.*, 2019). For example, in this view, donor organizations can play an important role by simply making transdisciplinary approaches a prerequisite for receiving funding.

Feedback from project partners at the end of the EAU4Food project indicates that most of the stakeholders believed that the transdisciplinary approach had indeed enriched the research process, compared to if they had followed more traditional methods. Noticeably, in all our case studies, local coordinating research teams primarily had a technical background, but were able to build, in cooperation with project partners, some of the necessary capacities and skills for organizing and managing the transdisciplinary process.

Overall, farmers, government staff and researchers considered the approach successful, giving those actors a voice who usually do not have a say, namely farmers and local government staff, and a chance to actively contribute to the research process and shape the research agenda. In our experience, the approach did not entirely question power relations, but provided genuine opportunities for cooperation and learning among different stakeholders.

Applying the transdisciplinary approach in the five case studies across Africa revealed its robustness—the approach could be applied under difficult conditions, as was seen in the 2013 Limpopo flood in Mozambique, the revolution in Tunisia and in the face of political tensions in Mali.

Given the relatively short duration of the project and the absence of a counterfactual, it is difficult to prove from the case study results whether the transdisciplinary approach applied in the EAU4Food research project has led to higher uptake than would have been the case had a traditional research approach been used. In any case, applying the transdisciplinary approach resulted in in-depth understanding of underlying innovation barriers. Oates *et al.* (2019), Hanafi *et al.* (2019) and Dolinska *et al.* (2019) show which barriers need to be specifically addressed in future planning and design of interventions. Having distinct platforms such as CoPs or LPAs, and their well-integrated modes in particular (CoP–LPA), have proven useful to gain specific contextual insights, as well as a broader view and, hence, to create a more holistic perspective, among all participants, of the innovation process (Musvoto *et al.*, 2015).

The experience from the EAU4Food project reveals that managing a transdisciplinary research project is a challenge on its own and is different from running classical research projects. Being stakeholder driven, such projects require a sizable commitment, patience and flexibility from all actors involved to accommodate upcoming demands and unforeseen priorities. This is particularly the case during the inception period of the project. Sufficient time must be set aside to interact substantially with CoP–LPA members. Using a structured protocol to guide all relevant steps that have to be followed is also essential to streamline the different contributions from different stakeholder groups (Musvoto *et al.*, 2015). The selection of expertise to be part of the research team should be kept open until the problem has been identified.

There is a need to establish future LPAs in such a way that they actually contribute to problem solving at a higher level and tackle elements of the enabling framework that suppress innovation. LPAs should also aim at agreeing a shared definition of development goals and sustainability targets to which the innovation of irrigated agriculture should contribute.

The composition of the stakeholder platforms such as CoP and LPAs and their integrated modes (CoP–LPA) must

be flexible enough to meet the given complexity and context, and must also include representatives from outside the primary production sphere, such as from agribusiness, the financial sector, regional planning and other decision-makers who have a bearing on smallholder farmers or water management.

Building trusting partnerships and transdisciplinary approaches in research for development and innovation takes time. Novel ways should be explored to develop larger strategic programmes that continue over an adequate period of time (>5 years) to provide an enabling framework, that allow for flexible involvement of actors and experts, and contain a strong political mandate to implement a transdisciplinary approach. Combining research instruments and development programmes will furthermore help to gain insights from research to optimize the transdisciplinary approach and develop adequate infrastructure and organizational structures at the same time. Institutionalizing and sustaining transdisciplinary research could be furthered by exploiting alternative funding models, such as revolving funds or long-term public–private partnership concepts.

Above all, the EAU4Food experiences reflected in this special issue emphasize that actual innovation on irrigated smallholder farms remains limited without sufficient improvement of the enabling environment and taking note of the wider political economy environment. The development of interventions cannot remain at the local farm-level scale but should correspond to specific contexts and given complexities at local, regional and national scales.

The set-up of EAU4Food led to a mix of methodological approaches including: in implementing transdisciplinary approaches, advancing individual assessment methods, and in efforts to increase crop production in the field. Future transdisciplinary research projects will certainly benefit from making a clearer distinction in focusing either on specific methodological aspects, or generating local capacity, or providing orientation in solving practical problems.

On the whole, all the participants in the EAU4Food project, including the research community, the farmers' community and higher-level stakeholders, emphasized the fact that the transdisciplinary approach provided valuable insights into the design of future interventions to increase agricultural production. Finally, the participants expressed great interest in continuing to participate in transdisciplinary research with the aim of finding solutions to problems related to irrigation development in the field.

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REFERENCES

- Albasha R, Jovanovic N, Cheviron B, Clercq WD, Mailhol JC. 2019. Optimizing tomato water and fertilizer uses in smallholder farms in South Africa using the Piloten model. *Irrigation and Drainage* **68**(S1). <https://doi.org/10.1002/ird.2071>.
- Botha N, Klerkx L, Small B, Turner JA. 2014. Lessons on transdisciplinary research in a co-innovation programme in the New Zealand agricultural sector. *Outlook on Agriculture* **43**(3): 219–223. <https://doi.org/10.5367/oa.2014.0175>.
- Burger P, Kamber R, Schindler RA, Henry S. 2003. Cognitive integration in transdisciplinary science: knowledge as a key notion. *Issues in Interdisciplinary Studies*. **21**: 43–73. <http://hdl.handle.net/10323/4400>.
- Burney JA, Naylor RL, Postel SL. 2013. The case for distributed irrigation as a development priority in sub-Saharan Africa. *Proceedings of the National Academy of Sciences* **110**(31): 12513–12517. <https://doi.org/10.1073/pnas.1203597110>.
- Calow RC, Ludi E, Tucker J. 2013. Achieving Water Security. In *Lessons from Research in Water Supply, Sanitation and Hygiene in Ethiopia*. Practical Action Publishing: Rugby, UK..
- Collier P, Dercon S. 2014. African agriculture in 50 years: smallholders in a rapidly changing world? *World Development* **63**: 92–101. <https://doi.org/10.1016/j.worlddev.2013.10.001>.
- Devaux A, Torero M, Donovan J, Horton D. 2018. Agricultural innovation and inclusive value-chain development: a review. *Journal of Agribusiness in Developing and Emerging Economies* **8**(1): 99–123. <https://doi.org/10.1108/JADEE-06-2017-0065>.
- Diawara B, Dicko M, Coulibaly Y, Kabirou N'Diaye M, Jamin JY, Poussin J-C. 2018. Perception by farmers of the determinants of irrigated rice yield in Mali. *Agronomy for Sustainable Development* **38**(6): 61. <https://doi.org/10.1007/s13593-018-0542-2>.
- Dicko M, Diawara B, Tangara B, Jamin J-Y, Rougier J-E, Bah S. 2019. Une approche participative pour améliorer la maintenance du réseau et la gestion de l'eau dans un périmètre irrigué au Mali. *Irrigation and Drainage* **68**: S1. <https://doi.org/10.1002/ird.2239>.
- Dionnet M, Kuper M, Hammami A, Garin P. 2008. Combining role-playing games and policy simulation exercises: an experience with Moroccan smallholder farmers. *Simulation and Gaming* **39**(4): 498–514. <https://doi.org/10.1177%2F1046878107311958>.
- Dolinska A, Oates N, Ludi E, Habtu S, Rougier JE, Sánchez-Reparaz M, Mosello B, Yazew E, Kifle M, Fissehaye D, Aregay G, Tamele HF, Barberá GG, d'Aquino P. 2019. Engaging farmers in a research project. Lessons learned from implementing the community of practice concept in innovation platforms in irrigation schemes in Tunisia, Mozambique and Ethiopia. *Irrigation and Drainage* **68**(S1). <https://doi.org/10.1002/ird.2222>.
- Ducrot R, Otake M, Riera A, Famba S, Nguenha R. 2018. Upscaling maintenance operations in a large-scale irrigation scheme to solve drainage issues: going beyond a managerial perspective. *Irrigation and Drainage* **67**(4): 582–593. <https://doi.org/10.1002/ird.2272>.
- Ducrot R, Leite M, Gentil C, Bouarfa S, Rollin D, Famba S. 2019. Strengthening the capacity of irrigation schemes to cope with flood through improved maintenance: a collaborative approach to analyse the case of Chókwè, Mozambique. *Irrigation and Drainage* **68**: S1. <https://doi.org/10.1002/ird.2229>.
- Fissahaye DY, Ritsema CJ, Solomon H, Froebrich J, van Dam JC. 2017. Irrigation water management: farmers' practices, perceptions and adaptations at Gumselassa Irrigation Scheme, north Ethiopia. *Agricultural Water Management* **191**: 16–28. <https://doi.org/10.1016/j.agwat.2017.05.009>.
- Food and Agriculture Organization of the United Nations (FAO). 2011. *The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk*. Earthscan: New York, USA.
- Habtu S, Erkossa T, Froebrich J, Tquabo F, Fissehaye D, Kidanemariam T, Xueliang C. 2019. Integrating participatory data acquisition and modeling of irrigation strategies to enhance water productivity in a small-scale irrigation scheme in Tigray, Ethiopia. *Irrigation and Drainage* **68**(S1). <https://doi.org/10.1002/ird.2235>.
- Hanafi S, Marlet S, Jamin JY, Imache A, Zairi A, Bahri H, Rougier JE, Bouarfa S. 2019. Participation in a complex and conflicting context: implementing a shared diagnosis in a northern Tunisia irrigation scheme. *Irrigation and Drainage* **68**(S1). <https://doi.org/10.1002/ird.2224>.
- Hoffmann V, Probst K, Christinck A. 2007. Farmers and researchers: how can collaborative advantages be created in participatory research and technology development? *Agriculture and Human Values* **24**(3): 355–368. <https://doi.org/10.1007/s10460-007-9072-2>.
- Intergovernmental Panel on Climate Change (IPCC). 2014. In Core Writing Team, Pachauri RK, Meyer LA (eds). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC: Geneva, Switzerland; p 151.
- Jovanovic N, Musvoto C, Clercq WD, Pienaar C, Petja B, Zairi A, Hanafi S, Ajmi T, Mailhol JC, Cheviron B, Albasha R, Habtu S, Yazew E, Kifle M, Fissahaye D, Aregay G, Habtegebreal K, Gebrekiros A, Woldu Y, Froebrich J. 2019. A comparative analysis of yield gaps and water productivity on smallholder farms in Ethiopia, South Africa and Tunisia. *Irrigation and Drainage* **68**(S1). <https://doi.org/10.1002/ird.2238>.
- Khadra R, Sagardoy JA, Taha S, Lamaddalena N. 2017. Participatory irrigation management and transfer: setting the guiding principles for a sustaining monitoring and evaluation system—a focus on the Mediterranean. *Water Resources Management* **31**(13): 4227–4238. <https://doi.org/10.1007/s11269-017-1741-3>.

- Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science* 7(Suppl. 1): 25–43. <https://doi.org/10.1007/s11625-011-0149-x>.
- Larson DF, Muraoka R, Otsuka K. 2016. Why African rural development strategies must depend on small farms. *Global Food Security* 10: 39–51. <https://doi.org/10.1016/j.gfs.2016.07.006>.
- Leemans R. 2017. Editorial overview: how to promote transdisciplinary, evidence-based sustainability solutions? *Current Opinion in Environmental Sustainability* 29: xii–xv. <https://doi.org/10.1016/j.cosust.2018.01.002>.
- Ludi E, Oates N. 2015. *An Evaluation of the Transdisciplinary Approach Implemented under the EAU4Food Project*. ODI: London, UK.
- Mason N, Ludi E, Rougier JE, Mtisi S, van Beek C. 2011. *Transdisciplinary Research Protocol—a Guidance Manual for EAU4Food Researchers*. ODI: London, UK.
- Matsushima S. 1966. *Crop Science in Rice. Theory of Yield Determination and its Application*. Fuji Publishing Co.: Tokyo, Japan.
- Meynard JM, Jeuffroy MH, Le Bail M, Lefèvre A, Magrini MB, Michon C. 2017. Designing coupled innovations for the sustainability transition of agrifood systems. *Agricultural Systems* 157: 330–339. <https://doi.org/10.1016/j.agsy.2016.08.002>.
- Michel C, Hearn S, Wuelsel G, Breu T. 2013. Maximising the impact of transdisciplinary research with a novel approach: ROMA (RAPID outcome mapping). In Michel C, Heim EM, Zimmermann AB, Herweg K, Breu T (eds). *Maximising the Impact of Research: the NCCR North–South Approach*. CDE: Bern; p 11–19.
- Miller TR, Wiek A, Sarewitz D, Robinson J, Olsson L, Kriebel D, Loorbach D. 2014. The future of sustainability science: a solutions-oriented research agenda. *Sustainability Science* 9(2): 239–246. <https://doi.org/10.1007/s11625-013-0224-6>.
- Mtisi S. 2011. Learning and practice alliance—an approach to research for better policy and practice. In *EAU4Food background note*. ODI: London, UK.
- Musvoto C, Mason N, Jovanovic N, Froebrich J, Tshovhote J, Nemakhavhani M, Khabe T. 2015. Applying a transdisciplinary process to define a research agenda in a smallholder irrigated farming system in South Africa. *Agricultural Systems* 137: 39–50. <https://doi.org/10.1016/j.agsy.2015.03.008>.
- Njoroge R, Birech R, Arusey C, Korir M, Mutisya C, Scholz RW. 2015. Transdisciplinary processes of developing, applying, and evaluating a method for improving smallholder farmers access to (phosphorus) fertilizers: the SMAP method. *Sustainability Science* 10(4): 601–619. <https://doi.org/10.1007/s11625-015-0333-5>.
- Oates N, Hisberg A, Rodríguez Ros J, Solomon H, Ludi E, Marlet S, Jamin JY. 2019. The implications of state intervention for self-governed irrigation schemes: insights from Tigray, Ethiopia. *Irrigation and Drainage* 68(S1). <https://doi.org/10.1002/ird.2121>.
- Pradeleix L, Bouarfa S, Bellon-Maurel V, Roux P. 2019. Assessing environmental impacts of groundwater irrigation using the life cycle assessment method: application to a Tunisian arid region. *Irrigation and Drainage* 68(S1). <https://doi.org/10.1002/ird.2241>.
- Ritzema HP, Thinh LD, Anh LQ, Hanh DN, Chien NV, Lan TN, Kselik RAL, Kim BT. 2008. Participatory research on the effectiveness of drainage in the Red River Delta, Vietnam. *Irrigation and Drainage Systems* 22(1): 19–34. <https://doi.org/10.1007/s10795-007-9028-0>.
- Sánchez-Reparaz M, Vente JD, Famba S, Rollin D, Dolinska A, Rougier JE, Tamele HF, Barberá GG. 2019. Innovative soil fertility management by stakeholder engagement in the Chókwè Irrigation Scheme (Mozambique). *Irrigation and Drainage* 68: S1. <https://doi.org/10.1002/ird.2054>.
- Scholz RW, Lang DJ, Wiek A, Walter AI, Stauffacher M. 2006. Transdisciplinary case studies as a means of sustainability learning: historical framework and theory. *International Journal of Sustainability in Higher Education* 7(3): 226–251. <https://doi.org/10.1108/14676370610677829>.
- Scholz RW, Steiner G. 2015a. The real type and ideal type of transdisciplinary processes: part I—theoretical foundations. *Sustainability Science* 10(4): 527–544. <https://doi.org/10.1007/s11625-015-0326-4>.
- Scholz RW, Steiner G. 2015b. The real type and ideal type of transdisciplinary processes: part II—what constraints and obstacles do we meet in practice? *Sustainability Science* 10(4): 653–671. <https://doi.org/10.1007/s11625-015-0327-3>.
- Scholz RW, Steiner G. 2015c. Transdisciplinarity at the crossroads. *Sustainability Science* 10(4): 521–526. <https://doi.org/10.1007/s11625-015-0338-0>.
- Senanayake N, Mukherji A, Giordano M. 2015. Re-visiting what we know about irrigation management transfer: a review of the evidence. *Agricultural Water Management* 149: 175–186. <https://doi.org/10.1016/j.agwat.2014.11.004>.
- Smith A, Snapp S, Chikowo R, Thorne P, Bekunda M, Glover J. 2017. Measuring sustainable intensification in smallholder agroecosystems: a review. *Global Food Security* 12: 127–138. <https://doi.org/10.1016/j.gfs.2016.11.002>.
- Spangenberg JH. 2011. Sustainability science: a review, an analysis and some empirical lessons. *Environmental Conservation* 38(3): 275–287. <https://doi.org/10.1017/S0376892911000270>.
- Stelman T, Nichols EG, James A, Bradford L, Ebersöhn L, Scherman V, Omidire F, Bunn DN, Twine W, McHale MR. 2015. Practicing the science of sustainability: the challenges of transdisciplinarity in a developing world context. *Sustainability Science* 10(4): 581–599. <https://doi.org/10.1007/s11625-015-0334-4>.
- Tucker J, Le Borgne E, Iotti M. 2013. Policy and practice influencing through research: critical reflections on RIPPLES’s approach. In Calow R, Ludi E, Tucker J (eds). *Achieving Water Security. Lessons from Research in Water Supply, Sanitation and Hygiene in Ethiopia*. Practical Action Publishing Ltd: Rugby, UK; p 171–193.
- van Breda J, Musango J, Brent A. 2016. Undertaking individual transdisciplinary PhD research for sustainable development: case studies from South Africa. *International Journal of Sustainability in Higher Education* 17(2): 150–166. <https://doi.org/10.1108/IJSHE-07-2014-0107>.
- Veldwisch GJ. 2015. Contract farming and the reorganisation of agricultural production within the Chókwè Irrigation System, Mozambique. *Journal of Peasant Studies* 42(5): 1003–1028. <https://doi.org/10.1080/03066150.2014.991722>.
- Wenger E. 1998. Communities of practice: learning as a social system. *Systems Thinker* 9(5): 2–3. <https://doi.org/10.1177/135050840072002>.
- World Bank. 2008. *World Development Report 2008: Agriculture for Development*. WTO: Washington DC, USA.
- Yoshida S. 1981. *Fundamentals of Rice Crop Science*. International Rice Research Institute: Los Banos.
- Young J, Mendizabal E. 2009. Helping researchers become policy entrepreneurs. How to develop engagement strategies for evidence-based policy-making. Briefing paper. ODI: London, UK.

ENDNOTES

- ¹ <https://www.prb.org/2016-world-population-data-sheet/>
- ² <http://siteresources.worldbank.org/INTAFRICA/Resources/africa-agribusiness-report-2013.pdf>
- ³ EAU4Food, European Union and African Union cooperative research to increase Food production in irrigated farming systems in Africa, European Commission, FP7, Grant agreement No. 265471.