Social-institutional problem dimensions of late blight and bacterial wilt of potato in Ethiopia

The contribution of social learning and
communicative interventions to collective action

Elias Damtew Assefa

Thesis committee

Promotor
Prof. Dr C. Leeuwis
Professor of Knowledge, Technology and Innovation
Wageningen University & Research

Prof. Dr P. C. Struik
Professor of Crop Physiology
Wageningen University & Research

Co-promotor
Dr B.C. van Mierlo
Associate professor, Knowledge, Technology and Innovation Group
Wageningen University & Research

Dr B Lemaga
Senior Scientist, International Potato Center
Addis Ababa, Ethiopia

Other members
Prof. Dr A. Dewulf, Wageningen University & Research
Dr P. Gildemacher – Royal Tropical Institute (KIT), Amsterdam
Dr. R. Rodela - Södertörn University, Sweden
Prof Dr E. Schulte Geldermann - University of Applied Sciences Bingen, Germany

This research was conducted under the auspices of the Graduate School of Social Sciences (WASS)

Social-institutional problem dimensions of late blight and bacterial wilt of potato in Ethiopia

The contribution of social learning and
communicative interventions to collective action

Elias Damtew Assefa

Thesis

submitted in fulfilment of the requirements for the degree of doctor
at Wageningen University & Research

by the authority of the Rector Magnificus,
Prof. Dr A.P.J. Mol,
in the presence of the
Thesis Committee appointed by the Academic Board
to be defended in public

on Tuesday 25 August 2020
at 1:30 p.m. in the Aula.

Elias Damtew Assefa

Social-institutional problem dimensions of late blight and bacterial wilt of potato in Ethiopia: The contribution of social learning and communicative interventions to collective action

200 pages

PhD thesis, Wageningen University, Wageningen, the Netherlands (2020).
With references, with summaries in English

ISBN: 978-94-6395-474-7
DOI: https://doi.org/10.18174/527740

Table of Contents

1

Chapter 1

General Introduction

Preamble

Improvements in the potato production system can be a pathway out of poverty in Ethiopia and Sub-Saharan Africa at large. It is a very important smallholder farmer crop, with a short cropping cycle, a potential for high yield per hectare, and serving both as a cash and food security crop (Hirpa et al., 2015; Kolech et al., 2015; Bymolt, 2014; Scott et al., 2013; Thiele et al., 2010). Diseases such as late blight and bacterial wilt are seriously undermining potato productivity, leading to a large gap between attainable and actual yield (Forbes, 2012). Potato farmers are suffering from recurrent outbreaks of late blight and persistent prevalence of bacterial wilt (Scott et al., 2013) making them the two most important diseases for potato growing farmers in tropical and subtropical regions, and in some warm temperate regions of the world. (Charkowsk et al., 2020; Olanya, 2001). Like many places in the developing world where these diseases occur, potato growing areas in Ethiopia are characterized by poverty and food insecurity (Bararyenya et al., 2018; Scott et al., 2013; Forbes, 2012). Poor disease management practices (including phytosanitation and cultural practices), limited access to technologies (e.g. resistant varieties, fungicides), poorly-organized seed systems and a fairly weak public extension system are among the most commonly stated factors contributing to the continued problem of late blight and bacterial wilt in Ethiopia (Kolech et al., 2015; Bymolt 2014; Hirpa et al., 2010; Gildemacher et al., 2009).

To find a sustainable solution to the problem of late blight and bacterial wilt, diverse governmental and non-governmental research and development initiatives promoted different management strategies (Abdurahman et al., 2017; Kassa, 2016; Gorfu et al., 2012; Mekonen et al., 2011). A detailed account of the different research, policy and practice related efforts for managing the diseases is described in the introduction sections of Chapter 2 and Chapter 3 of this thesis.

This Ph.D. study is part of this continued effort in the research frontier that aims to broaden the understanding of the problem situation, and the investigation of alternative management strategies for the diseases (Abdurahman et al., 2017; Kassa, 2016; Kassa and Eshetu, 2008; Kuarabachew et al., 2007; Lemaga et al., 2005). It is a specific case study in the broader EVOCA (*Responsible Life-Science Innovations For Development In The Digital Age: Environmental Virtual Observatories for Connective Actio*n) research program that seeks to leverage life-science knowledge, digital technologies, citizen science and responsible innovation to deal with crop, water, livestock and disease management challenges in Africa (Cieslik et al., 2018). Positioned in the crop disease management component of the program, this study set out to understand the problem of late blight and bacterial wilt with a social-technical lens, and to explore the roles that different social-technical interventions play in the management of crop diseases, particularly late blight. Within this broader objective, the study also examines prospects for digital technologies as enablers of social-technical practices in the management of the diseases.

Problem description

The management of crop diseases has been the center of research attention in different disciplines and research fields. The three subsections under this problem description review three dominant research domains that shape perspectives in the problematization of crop diseases such as late blight and bacterial wilt, and their management. Knowledge gaps within the different domains are highlighted and used to situate the research topics addressed in the different chapters of the thesis.

A technology perspective to crop disease management

Various crop protection and extension literatures emphasize the fact that causal agents of many crop diseases, including *Phytophthora infestans,* causing late blight, and *Ralstonia solanacearum,* causing bacterial wilt, spread from plant to plant (e.g. Burke, 2017; Yuliar et al., 2015; Kirk and Wharton, 2014; Miller et al., 2006). This literature domain dwells on rich information on a wide range of biophysical information about crop diseases, such as disease development, symptoms, and spreading mechanisms to promote technical/ technological management solutions (Cooke et al., 2011; Vasse et al., 2005; Erwin and Ribeiro, 1996; Hayward, 1991). The problem of crop disease is understood from the classical notion of the 'disease triangle' whereby the disease is mainly explained as an outcome of intricate interactions between a pathogen, a host and the abiotic environment. The role of farmers is regarded as the application of proposed farm-level technical management methods (e.g. cultural methods like the spraying of chemicals, host resistance) that modify one or more of these interactions to make it (un)suitable for disease development (Yuliar et al., 2015; Champoiseau et al., 2010; Oor, 2003)

Approaches to crop disease management are, therefore, mainly geared towards the adoption or use of different types of technologies or a combination of technologies or technical management practices that can assist farmers in keeping their individual plots free from diseases (Devaux et al., 2014; Kromann et al., 2014; Parsa et al., 2014). The main goal is to develop promising disease management technologies and promoting their adoption with a general expectation that if everyone implements the recommended management practice(s), then everyone can manage the diseases (Carisse and McNealis, 2019; Forbes, 2012). Insufficient training and technical support to farmers and, hence, low farmer capacity to understand and manage crop diseases are regarded as the major obstacles to the adoption or effective use of recommended crop disease management practices (Bymolt, 2014; Devaux et al., 2014; Forbes, 2012; Andrade-Piedra et al., 2009).

A major weakness in this domain is a failure to appreciate crop disease management as a social-technical phenomenon that goes beyond isolated technological practices of individual farmers (Oscar et al., 2019; Van de Fliert et al., 2003; Campilan, 2002). In this regard, there exists a clear lack of perspective on the interdependent and collective nature of crop disease management and this body of literature provides little insight into the relevant social and organizational (re)configurations that might be required to collectively combat crop diseases.

A collaborative and collective action perspective to crop disease management

Numerous studies approached the crop disease management problem as a collaborative and collective action problem (e.g. Bagavathiannan et al., 2019; Oscar et al., 2019; Pacilly et al., 2018, 2016; Rodenburg et al., 2015; van de Fliert et al., 2007; Campilan, 2002). Many of these studies are inspired by perspectives on collaboration problems in the management of natural resources either by interdependent individuals or by a group of responsible actors (McDougall et al., 2013; Pahl-Wostl 2009; Kellert et al., 2000; Maarleveld and Dangbegnon 1999). The basic tenet is that managing crop diseases as shared problems requires a change in practices in the technical and the social sphere. On the one hand, relevant technical knowledge on the biophysical/epidemiological nature of diseases and on available management options is key in informing technical management practices (Van de Fliert et al., 2002; Nelson et al., 2001). On the other hand, the management of shared problems requires a re-ordering in social organizations that shape and modify social practices (Bagavathiannan et al., 2019; Pacilly et al., 2016). Such change in relevant technical knowledge and forms of social organization is expected to be fostered by participatory learning approaches such as social learning, farmer field schools, and Community IPM (Integrated Pest Management) programs (Van de Fliert et al., 2007, 2002; van de Fliert et al., 2002, Campilan, 2002; Olanya et al., 2010; Nelson et al., 2001). What appears to be shared by the different learning perspectives in this crop disease management literature domain is that it does not seek to explain how or why learning occurs, especially in regard to issues of relations, conflict or negotiation. There are usually predefined learning outcomes and what is learned or not learned is evaluated or studied against those outcomes (e.g. Oscar, 2019; Pacilly et al., 2018; Van de Fliert et al., 2002; Van de Fliert et al., 1997). Knowledge acquisition and forging new forms of social relations is rarely studied as a dynamic and evolving process towards change in (collective) practices. Consequently, the litrature largely fails to give important insights into salient learning processes of knowledge sharing, negotiation of agreements, conflict resolution or convergence of goals (Bentley et al., 2018; Beers et al., 2016; Leeuwis and Pyburn, 2002) that trigger change in technical and social disease management practices of people. Following Reeds et al., (2010) and others, this thesis deems that tracking or studying processes through which social learning occurs is key not only to understand how people learn in a particular context but also to continuously adapt learning processes towards collective action in the management of crop diseases (Van Mierlo and Beers, 2018; Beers et al., 2016; Pahl-Wostl et al., 2007).

A public bad perspective to crop disease management

A 'public bad' management perspective to crop disease management emanates from framing a crop disease as one among the many types of public bads such as infectious and invasive species, microbial resistance to antimicrobial agents, global warming and air pollution (Costello et al., 2017, Reeves et al., 2017; Bell et al., 2016; Milinski et al., 2008). Highlighting biophysical and/or ecological features of crop diseases, crop disease management is regarded as the management of a public bad whereby individuals face the dilemma of contributing to collective management or free-ride on the management efforts of others (Reeves et al., 2017; Bell et al., 2016). Having its entire focus on collaboration deficits among interdependent individuals or communities, a central research topic in this domain is on understanding the role of social/behavioral information, interactive communication and regulatory institutions in overcoming collective action problems (Six et al., 2015; Zhang et al., 2014; Ostrom, 2012). In doing so, the studies discern the role of information from that of interactive communication which adds to the understanding on when and how a particular type of information or communication could facilitate or hinder collective action in a particular context (Opdam et al., 2016; Poteete and Ostrom, 2012).

It is argued that collective action problems can be effectively managed if interdependent community members are able to install and maintain information flows, peer-to-peer monitoring and open communication channels (Leeuwis et al., 2018; Smith, 2010, Ostrom 1998). In this regard, there exists a large and growing body of literature that assesses the effect of peer-to-peer monitoring and interactive communication among community members in overcoming collective action problems (Cabrales et al., 2016; Reuben and Riedl, 2013; Smith, 2010; Milinski et al., 2008).

What appears to receive very scant attention is the role of technical information, such as information on interdependency resulting from the biophysical features of diseases, in dealing with collective action problems. Moreover, plausible explanations for the underlying mechanisms affecting how different types of information and communication practices influence collective action performance are largely missing. As much as there is widespread agreement that information and/or communication influence(s) collective action, there is little insight as to how it does this (Poteete and Ostrom, 2008; Cardinas and Ostrom, 2004).

Central research question

Given the critique on the technology-oriented perspective, this thesis first aims to broaden the understanding of the problem of late blight and bacterial wilt with a social-technical lens. Likewise, informed by the knowledge gaps on learning processes and on approaches to information and communication practices in the collective management of crop diseases, the thesis also investigates how and to what extent different types of learning and communicative interventions contribute to the collective management of crop diseases with particular emphasis on late blight. In this way, late blight is used as a case to draw lessons relevant for the management of the disease but also relevant to crop disease management as a collective action problem in general.

Hence, the main research question addressed is:

What are the key technical and social-institutional problem dimensions in the management of potato late blight and bacterial wilt in Ethiopia, and how does a confluence of social learning, information and communication practices contribute to collective action in the management of late blight?

Specific research questions:

1. How do actors' view the technical and social-institutional problem features of late blight and bacterial wilt and with what implication to the management of the diseases?

2. What is the role of farmers' knowledge and associated practices in the management of the late blight and bacterial wilt?
3. How does social learning contribute to farmers' collective action in the management of late blight?

4. How and to what extent do different types of communicative intervention influence farmers' collective action in the management of late blight?

Key concepts framing the thesis

Section 1.4.1. introduces concepts used to frame the first two specific research questions or the diagnostic phase of the main research question. Section 1.4.2. covers concepts employed for the third and fourth specific research questions or the intervention phase of the main research question.

Diagnosis phase: understanding key technical and social-institutional problem dimensions

In the diagnosis phase, two types of studies were conducted that explored (1) broader technological and socio-institutional problems in the management of the diseases at a systemic level, and (2) the knowledge and (collective) practices of farmers regarding the management of the diseases. In this respect, an understanding of the broader systemic constraint is complimented by a further study on the knowledge and practices of farmers that paved the way for the 'intervention' phase of the research. Conceptual perspectives from systems thinking, knowledge and human practices are employed in this diagnostic phase.

Systems thinking

Perspectives from systems thinking are used to unravel the wider technical and institutional problem dimensions of late blight and bacterial wilt management (*Research question 1*). The technical dimension relates to technical practices in disease diagnosis and in disease management techniques (Pernezny et al., 2016; Van der Plank, 2013). The institutional dimension falls into formal institutions or informal institutions that shape interactions in the system (Krueger and Gibbs, 2010; Checkland, 2002; Röling and Leeuwis, 2001). Anchoring on different technical and institutional problem dimensions, a soft systems lens is used to understand how actors involved in the management of crop disease view the problems and respond to those perceived problems. According to Senge (2006), this can be assessed from the way a problem situation and a response to it is explained by people. The explanation can be a reactive one based on events that usually lead to practicing superficial or symptomatic solutions. It can also be a generative one based on root causes of problems that helps identifying and applying fundamental or long term solutions. This perspective guided the analysis of the key technical and institutional problem dimensions of late blight and bacterial wilt in light of actors' views and responses to the problem situation.

Knowledge and practice

Different epidemiological and management aspects of late blight and bacterial wilt are linked to different but complementary types of knowledge to investigate farmers' knowledge and practices about the diseases (*Research question 2*). Following the seminal work of Lundvall and Johnson (1994) on the constitution of useful knowledge in learning economies, this study embraces the distinction between four different kinds of knowledge. *Know-what* refers to knowledge about 'facts'. *Know-why* is about scientific knowledge of principles and laws on how things operate in nature or in society. *Know-how* refers to skills or the capability to do something. *Know-who* covers a mix of different kinds of (social) skills and information about who knows what including the formation of special social relationships. It is also contended that relevant knowledge shapes disease management only if it is integrated into farmers' daily practices.

Practices are approached as patterns of human action that are defined or shaped by factors such as perception about ones' competence, views about consequences of actions, goals or aspirations and beliefs about the expectations of others (Shove et al., 2012; Leeuwis, 2004). It is emphasized that knowledge needs to be meaningful in a particular context to be translated into daily practice. Such a perspective on practice shaped the investigation on how different late blight and bacterial wilt management practices of farmers are informed by the knowledge about them, which is suggestive of the type(s) of learning processes that might be required for shaping knowledge and (collective) practices.

Intervention phase: the role of social learning, information and communication practices in collective action

Aggregating lessons from the findings of the diagnostic phase, the intervention phase tackled the third and fourth research questions. A process-oriented social learning perspective is employed to answer the third research question. Communication perspectives from different disciplines are integrated to address the fourth research question. In doing so, the study complemented the social learning study by separately analyzing the role of information and interactive communication which are interwoven in social learning processes.

Social learning

Collective management of crop diseases is not simply a matter of technological innovation, it equally requires numerous changes in the social-organizational sphere. By implication, disease management interventions need to be adapted not only to the technological context but also to the social context (Leeuwis and Pyburn 2002). Inducing these social-technical co-evolutionary change processes entails a cyclical, interactive and iterative mode of learning in which the integration of knowledge production, new forms of social relations and action are creatively facilitated (Bentley et al. 2018; Beers et al., 2016). Social learning is, therefore, a process of building and sustaining capacities in technical knowledge (about the material/biophysical aspect of diseases), and the re-ordering of institutions and forms of social relations in the management of crop diseases. Drawing on perspectives from well-known learning traditions (Bentley et al. 2018; Reed, 2010), a process-oriented social learning perspective is applied to study learning processes towards collective action in *Research question 3*. Social learning is approached as a communicative process in which new or changed technical knowledge, social relations and suggested actions become aligned.

Communication and communicative practices

The last empirical study of the thesis (*Research question 4*) is informed by communication perspectives in agricultural/rural innovation studies (Peng et al., 2018; Leeuwis and Aarts, 2011; Klerkx and Leeuwis, 2008; Leeuwis, 2004) and studies the management of public goods/bads (D'Exelle et al., 2012; Ostrom, 2012; Balliet, 2010). In earlier adoption and diffusion theories, communication was primarily looked at as an intermediary function between science and societal users (Rogers, 1995; Petty and Cacioppo 1986). The theory and practice of communication is mainly about the facilitation of adoption or diffusion of a ready-made innovation (Leeuwis and Aarts, 2011).

Together with the evolution in thinking about agricultural innovation, communication has a much broader intermediary role such as creating a discursive space for learning, negotiation, and conflict management among interdependent entities (Leeuwis and Aarts, 2011). This is a perspective developed and applied in a multi-actor setting and the case context of this study involves individuals who are interdependent on their efforts in managing late blight. Accordingly, the study employed a perspective from behavioral economics on the role of communication in arranging collective management of public bads. The opportunity to communicate is viewed as a mechanism that enables individuals to deal with their collective problem through coordinating collective strategies, to deal with free-riding behaviors or to develop a sense of shared norm and identity (D'Exelle et al*.,* 2012; Garicano and Wu, 2012; Balliet, 2010).

In any type of communicative intervention, the medium of communication has a number of enabling or constraining functional qualities (Leeuwis 2004). ICTs (Information Communication Technologies), particularly, Social Media and related mobile phone platforms can play meaningful roles in facilitating communication among spatially and temporally distributed individuals (Bennet and Segerberg 2012). These perspectives on communication and communicative practices guided the investigation of the role of different types of communicative interventions on the collective management of late blight among interdependent farmers.

Research design

The research design presents the overall strategy followed during the research journey to answer the different research questions as validly and accurately as possible (Kumar, 2019). A case study approach cuts across the different research topics of the thesis whereby broader inferences are made on crop disease management as a collective action problem. Case study is a suitable approach to explore a broad scope of complex issues, particularly when human behavior and social interactions are central to understanding topics of interest (Harrison et al., 2017). Within a case study, multiple methods of study designs, data collection and analysis techniques might be applied (Kumar, 2019), correspondingly, a mix of different study designs, data collection and analysis methods are employed (Table 1.1) to answer the research questions in the different chapters of the thesis. The next section gives an overview of the study designs used in the thesis; however, more details are provided in the different chapters of the thesis.

Study design

Exploratory

The diagnostic studies followed an *exploratory* study design. Exploratory research is often conducted to establish an understanding of an existing problem situation and is especially useful to investigate a problem that is not clearly defined (Mohajan, 2018). The exploratory studies conducted in the diagnostic phase of the research were instrumental in gaining in-depth insight into the problem situation and informing the later research undertakings of this study.

Action research

The essence of action research is the design of some form of intervention strategy following a good understanding of a problem in which an exploratory stance is adopted (Coghlan and Miller., 2014). The intervention (the 'action' in action research) is carried out while at the same time pertinent information for a research inquiry is generated in various forms (Reason and Bradbury, 2001). Informed by findings in the exploratory phase, a social learning intervention was designed and implemented among farmers. The social learning provided the arena whereby learning concerning the different problem dimensions of late blight management unfolded and was captured to answer the research inquiry.

Experiment

A framed field game experiment was designed to investigate the role of different types and combinations of communicative interventions on the collective action performance of farmers. A properly designed and executed experiment can provide strong evidence of what certain interventions actually cause or, if implemented, would cause (Archibald and Newhouse, 1980). Different combinations of experiential conditions were created around three types of communicative interventions: 1) provision of *technical information* about interdependency from the risks and benefits of individual late blight management practices, 2) provision of *monitoring information* about the management practice (spraying) of other farmers, and 3) opportunities for *interactive communication* among farmers. The experiment was used to measure the effect of the communicative interventions and to understand the mechanisms underlying their effect on farmers' collective action performance.

Table 1.1: Overview of the study designs, data collection and analysis techniques used in the different empirical chapters.

Research phase	Research questions	Chapter in the thesis	Study design	Data collection methods	Data analysis
Diagnostic phase	Research question 1	Chapter 2	Exploratory	Multi-stakeholder workshop; In-depth interviews	Content analysis of stakeholders' interviews along multiple problem dimensions
	Research question 2	Chapter 3	Exploratory	Survey; In-depth interviews	Cross-sectional analysis of farmers knowledge and practices
Intervention phase	Research question 3	Chapter 4	Action research	Participant observation; Documentation of facilitated group discussions	Discourse analysis of farmers' conversations
	Research question 4	Chapter 5	Experimental/ framed field game	In-depth interviews; Framed field game	Cross-sectional comparative analysis of farmers' collective action performance; Content analysis of interviews and farmers' conversations

Data collection

Multiple data collection techniques are employed in the thesis to generate qualitative information and quantitative data. More details on the different data collection methods are presented in the different chapters of the thesis.

Multi-stakeholder workshop

During the first diagnostic phase, a multi-stakeholder workshop was organized to jointly explore, prioritize and categorize a range of technical and socio-institutional problems in the management of crop diseases in general and that of late blight and bacterial wilt in particular. A problem diagnostic method, Rapid Appraisal of Agricultural Innovation System (RAAIS), was adopted to systematically identify and sort the different problem dimensions (Schuts et al., 2015). Different stakeholders that are involved in the management of crop diseases and that are found at national, regional and district levels took part in the workshop.

In-depth interviews

In-depth interviews were important data generation techniques for Chapter 2, Chapter 3 and Chapter 5 of the thesis. For Chapter 2, the interviews were conducted with stakeholders who took part in the workshop and who were identified during the workshop. The interviews were used to capture more in-depth narratives of stakeholders around problems identified during the workshop. Similarly, for Chapter 3, interviews were done to triangulate and complement the findings of survey data that was used in the same chapter. For Chapter 5, interviews were used to generate qualitative information that was used to explain the underlying mechanisms behind the effect of the communicative interventions on the collective action performance of farmers.

Participant observation

Observation served as an important data collection technique especially during the action research in Chapter 4. The writer of this thesis was a participant and an observant whereby he, together with other experts, facilitated and animated discussions during the action research and learning cycle. There was a high degree of flexibility in the processes and rigorous documentation of participants' communications and (inter)actions served as a source of data for studying the learning and change processes in the management of late blight.

Cross-sectional survey

To be able to answer the research questions posed in Chapter 3, a survey was conducted with 261 farmers. A questionnaire was administered to respondents to collect information about their socio-economic characteristics and their knowledge and practices concerning late blight and bacterial wilt management.

Gamification

A framed-field game was designed and used to generate data about farmers' late blight management practices/decisions when exposed to the different game experimental conditions (communicative interventions) as examined in Chapter 5. An aggregation of individual decisions to spray or not to spray fungicide was used to study the effect of the different communicative interventions on farmers' collective action in managing the disease.

Data analysis

Various data analysis techniques were employed in the different chapters of the thesis. Informed by the conceptual frameworks developed in the different chapters, a deductive content analysis technique dominates the analysis of the qualitative information in all empirical chapters. Nevertheless, an inductive approach to content analysis was also integrated in some of the chapters to identify emerging themes from the data.

In Chapter 2, the information on the views and practices of actors were coded according to different technical and institutional thematic lines. The coded content was then analyzed based on the operational definitions, bringing forward what constitutes or does not constitute a systemic understanding. In the same vein, the theoretical framing in Chapter 4 on social learning as a communicative process that aligns knowledge, relations and actions dictated the analysis of data segments in peoples' discourses for evidences of social learning. In Chapter 5, a content analysis of farmers' interviews and voice records was deductively conducted for content on different conceptual propositions on how interactive communication can influence collective action performance in the management of late blight. However, the same data was also inductively analyzed and emergent themes on farmers' understanding of interdependency and adaptation of management decisions based on behaviors of others were presented in the chapter. A qualitative analysis software, Atlas.ti, was used in the systematic coding and analysis of the qualitative data.

In Chapter 3, a cross-sectional analysis was performed on farmers' knowledge and practices of late blight and bacterial wilt management. Descriptive (percentage, frequency, mean) and inferential (Chi-square) statistics were used to make inferences on differences in farmers' knowledge of and practices for the management of the diseases among different farmer categories and study districts. The statistical analysis was done using SPSS (Version 22) software. Similarly, in Chapter 5, a cross-sectional comparative analysis was done amongst farmer groups exposed to different communicative intervention conditions. The analysis compared the effect of the different types of communicative intervention on the collective action performance of farmers in managing late blight. The comparison of collective action performance under the different types of communicative interventions was based on a regression run in STATA version 15.1 software.

Outline of the thesis

Following the four research questions, the thesis has four empirical chapters (Chapters 2, 3, 4 and 5) and begin with a general introduction chapter (Chapter 1) and ends with a synthesis chapter (Chapter 6).

As an initial exploratory phase of the wider disease management system in Ethiopia, *Chapter 2* aims to investigate actors' understanding of the problem of late blight and bacterial wilt management along several technical and socio-institutional problem dimensions and its implication for the management of the diseases at a collective level. The chapter provides useful insights into several interrelated technical and institutional problems, overlooked by the different actors, that are contributing to the continued problem of the diseases. The chapter paves the way for a further investigation of the knowledge and practices of farmers and the exploration of a bottom-up or community focused disease management intervention.

Building on findings of *Chapter 2* on the existing information and knowledge sharing culture and issues of interdependency, *Chapter 3* deepens the understanding of the problem situation by assessing the role of farmers' knowledge and associated practices to problems in the management of late blight and bacterial wilt. The chapter explores farmers' knowledge about the diseases and how their knowledge is informing their (collective) disease management practices. It also suggests how fostering a simultaneous change in the technical and social practices of farmers through learning, monitoring, and institutional mechanisms could contribute to the collective management of the diseases.

In view of findings in *Chapter 2* and *Chapter 3,* and taking late blight as a case, *Chapter 4* demonstrates social learning as a communication process in which new knowledge, relations and suggested actions become aligned and contribute to collective action in the management of the disease. By taking a process-oriented perspective to learning, the chapter highlights how social learning contributes to collective agreements and implementation of new management practices and also the emergence of regulatory institutions.

Chapter 5 takes a broader perspective on communicative practices that discern the role of information provision from that of interactive communication. The chapter demonstrates how and to what extent the provision of different types of information and creating opportunities for interactive communication affect the collective action performance of farmers in the management of late blight.

Chapter 6 summarizes the key findings of the research questions addressed in the four empirical chapters and discusses cross-cutting or overarching themes featured in the different chapters of the thesis. The chapter finally makes recommendations for policy, practice and future research.

References

Abdurahman, A., Griffin, D., Elphinstone, J., Struik, P.C., Schulz, S., Schulte-Geldermann, E., Sharma, K., 2017. Molecular characterization of Ralstonia solanacearum strains from Ethiopia and tracing potential source of bacterial wilt disease outbreak in seed potatoes. Plant Pathol. 66, 826–834.

Andrade-Piedra JL, Cáceres PA, Pumisacho M, Forbes GA (2009) Humans: the neglected corner of the disease tetrahedron—developing a training guide for resource-poor farmers to control potato late blight. Acta Hort 834:111–122

Archibald, R. W., & Newhouse, J. P., 1980. Social experimentation: Some whys and hows. R-2479-HEW. Santa Monica, Calif.: Rand Corp.

Arora, R.K., Sharma, S. and Singh, B.P., 2014. Late blight disease of potato and its management. *Potato Journal*, *41*(1).

Bagavathiannan, M.V., Graham, S., Ma, Z., Barney, J.N., Coutts, S.R., Caicedo, A.L., De Clerck-Floate, R., West, N.M., Blank, L., Metcalf, A.L. and Lacoste, M., 2019. Considering weed management as a social dilemma bridges individual and collective interests. *Nature plants*, *5*(4), p.343.

Balliet, D., 2010. Communication and cooperation in social dilemmas: A meta-analytic review. *Journal of Conflict Resolution*, *54*(1), pp.39-57.

Bararyenya, A., Nahayo, P.C., Nduwimana, A., Niyonzima, P., Nyawakira, D., Sindihebura, J.P., Vyizigiro, E., Ndayishimiye, V. and Haverkort, A.J., 2018. Assessment of Opportunities for Burundian Small-Scale Potato Farmers to Increase Productivity and Income. *Potato Research*, *61*(1), pp.73-88.

Bell, A., Zhang, W. and Nou, K., 2016. Pesticide use and cooperative management of natural enemy habitat in a framed field experiment. *Agricultural Systems*, *143*, pp.1-13.

Beers, P.J., Van Mierlo, B. and Hoes, A.C., 2016. Toward an integrative perspective on social learning in system innovation initiatives. *Ecology and Society*, *21*(1).

Brymer, A.L.B., Wulfhorst, J.D. and Brunson, M.W., 2018. Analyzing stakeholders' workshop dialogue for evidence of social learning. *Ecology and Society*, *23*(1).

Burke, J.J., 2017. Growing the Potato Crop. Vita, Equity House, Upper Ormond Quay, Dublin, Ireland.

Bymolt, R., 2014. Report: Creating Wealth with Seed Potatoes in Ethiopia (FIGG/39).

Cabrales, A., Feri, F., Gottardi, P. and Meléndez-Jiménez, M., 2016. Can there be a market for cheap-talk information? Some experimental evidence.

Campilan, D., 2002. Linking social and technical components of innovation through social learning. *Wheelbarrows Full of Frogs: Social Learning in Rural Resource Management. Assen, The Netherlands*, 135-146.

Cárdenas, J.C. and Ostrom, E., 2004. What do people bring into the game? Experiments in the field about cooperation in the commons. *Agricultural systems*, *82*(3), pp.307-326.

Carisse, O. and McNealis, V., 2019. Development of Action Threshold to Manage Common Leaf Spot and Black Seed Disease of Strawberry Caused by Mycosphaerella fragariae. *Plant disease*, *103*(3), pp.563-570.

Champoiseau, P., Jones, J., Momol, T., Pingsheng, J., Allen, C., Norman, D., Harmon, C., Miller, S., Schubert, T., Bell, D., 2010. Ralstonia Solanacearum Race 3 Biovar 2 Causing Brown Rot of

Potato, Bacterial Wilt of Tomato and Southern Wilt of Geranium. American Phytopathological Society, Madison. Available at http://plantpath.ifas.ufl.edu/rsol/NRI_Project/Projectsummary.html (Accessed April 2020).

Charkowski, Amy, Kalpana Sharma, Monica L. Parker, Gary A. Secor, and John Elphinstone., 2020. "Bacterial Diseases of Potato." In *The Potato Crop*, pp. 351-388. Springer, Cham.

Checkland, P., 2000. Soft systems methodology: a thirty year retrospective. *Systems research and behavioral science*, *17*(S1), pp.S11-S58.

Cieslik, K. J., Leeuwis, C., Dewulf, A. R. P. J., Lie, R., Werners, S. E., Van Wessel, M., P. Feindt, and 984 Struik, P. C., 2018. Addressing socio-ecological development challenges in the digital age: Exploring 985 the potential of Environmental Virtual Observatories for Connective Action (EVOCA). *NJAS*-986 *Wageningen Journal of Life Sciences*, *86*, 2-11.

Coghlan, D. and Brydon-Miller, M. eds., 2014. *The SAGE encyclopedia of action research*. Sage.

Cooke, L., Schepers, H., Hermansen, A., Bain, R., Bradshaw, N., Ritchie, F., Shaw, D., Evenhuis, A., Kessel, G., Wander, J., 2011. Epidemiology and integrated control of potato late blight in Europe. Potato Res. 54, 183–222.

Costello, C., Querou, N. and Tomini, A., 2017. Private eradication of mobile public bads. *European Economic Review*, *94*, pp.23-44.

D'Exelle, B., Lecoutere, E. and Van Campenhout, B., 2012. Equity-efficiency trade-offs in irrigation water sharing: evidence from a field lab in rural Tanzania. *World Development*, *40*(12), pp.2537-2551.

Peng, X., Hendrikse, G. and Deng, W., 2018. Communication and innovation in cooperatives. *Journal of the Knowledge Economy*, *9*(4), pp.1184-1209.

Devaux, A., Kromann, P., Ortiz, O., 2014. Potatoes for sustainable global food security. Potato Res. 57, 185–199.

Erwin, D.C., Ribeiro, O.K., 1996. Phytophthora Diseases Worldwide. American Phytopathological Society (APS Press).

Forbes, G.A., 2012. Using host resistance to manage potato late blight with particular reference to developing countries. *Potato Research*, *55*(3-4), pp.205-216.

Garicano, L. and Wu, Y., 2012. Knowledge, communication, and organizational capabilities. *Organization science*, *23*(5), pp.1382-1397.

Gildemacher, P.R., Kaguongo, W., Ortiz, O., Tesfaye, A., Woldegiorgis, G., Wagoire, W.W., Kakuhenzire, R., Kinyae, P.M., Nyongesa, M., Struik, P.C., Leeuwis, C., 2009a. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Res. 52, 173–205.

Gorfu, D., Woldegiorgis, G., Kassa, B., 2012. Bacterial wilt an emerging threat to ethiopian potato industry. In seed potato tuber production and dissemination: experiences, challenges and prospects. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination Mar (pp. 211–222).

Harrison, H., Birks, M., Franklin, R. and Mills, J., 2017, January. Case study research: Foundations and methodological orientations. In *Forum Qualitative Sozialforschung/Forum: Qualitative Social Research* (Vol. 18, No. 1).

Hayward, A., 1991. Biology and epidemiology of bacterial wilt caused by Pseudomonas solanacearum. Annu. Rev. Phytopathol. 29, 65–87.

Hirpa, A. H., Meuwissen, M. P., Lommen, W. J., Tsegaye, A., Struik, P. C., & Lansink, A. G. O. , 2015. Least-cost seed potato production in Ethiopia. *Potato research*, *58*(3), 277-300.

Kassa, B., 2016. Potato bacterial wilt management in the Central Highlands of Ethiopia. Ethiopian J. Agric. Sci. 26 (2), 83–97.

Kassa, B., Eshetu, B., 2008. Potato disease management. Pages 79–96. In: Woldegiorgis, G., Gebre, E., Lemaga, B. (Eds.), Root and Tuber Crops: The Untapped Resources. Ethiopian Institute of Agricultural Research, Addis Ababa.

Kellert, S.R., Mehta, J.N., Ebbin, S.A. and Lichtenfeld, L.L., 2000. Community natural resource management: promise, rhetoric, and reality. *Society & Natural Resources*, *13*(8), pp.705-715.

Kirk, W.W., Wharton, P.S., 2014. 11 fungal and bacterial disease aspects in potato production. Potato: Botany, Prod. Uses 167.

Klerkx, L. and Leeuwis, C., 2008. Matching demand and supply in the agricultural knowledge infrastructure: Experiences with innovation intermediaries. *Food policy*, *33*(3), pp.260-276.

Kolech, S. A., Halseth, D., De Jong, W., Perry, K., Wolfe, D., Tiruneh, F. M., & Schulz, S., 2015. Potato variety diversity, determinants and implications for potato breeding strategy in Ethiopia. *American Journal of Potato Research*, *92*(5), 551-566.

Kromann, P., Miethbauer, T., Ortiz, O. and Forbes, G.A., 2014. Review of potato biotic constraints and experiences with integrated pest management interventions. In *Integrated pest management* (pp. 245-268). Springer, Dordrecht.

Krueger, R. and Gibbs, D., 2010. Competitive global city regions and 'sustainable development': an interpretive institutionalist account in the South East of England. *Environment and planning A*, *42*(4), pp.821-837.

Kuarabachew, H., Assefa, A., Hiskias, Y., 2007. Evaluation of Ethiopian isolates of Pseudomonas fluorescens as biocontrol agent against potato bacterial wilt caused by Ralstonia (Pseudomonas) solanacearum. Acta Agric. Solvenica 90 (December (2)), 125–135.

Kumar, R., 2019. *Research methodology: A step-by-step guide for beginners*. Sage Publications Limited.

Leeuwis, C., Cieslik, K.J., Aarts, M.N.C., Dewulf, A.R.P.J., Ludwig, F., Werners, S.E. and Struik, P.C., 2018. Reflections on the potential of virtual citizen science platforms to address collective action challenges: Lessons and implications for future research. *NJAS-Wageningen Journal of Life Sciences*, *86*, pp.146-157.

Leeuwis, C. and Aarts, N., 2011. Rethinking communication in innovation processes: creating space for change in complex systems. *Journal of agricultural education and extension*, *17*(1), pp.21-36.

Leeuwis, C., 2004. Communication for Rural Innovation. Rethinking Agricultural Extension, 3rd ed. Blackwell Science, Oxford

Leeuwis, C. and Pyburn, R., 2002. Social learning for rural resource management. *Wheelbarrows full of frogs: Social learning in rural resource management*, pp.11-21.

Lemaga, B., Kakuhenzire, R., Kassa, B., Ewell, P.T., Priou, S., Allen, C., Prior, P., Hayward, A., 2005. Integrated Control of Potato Bacterial Wilt in Eastern Africa: the Experience of African Highlands Initiative. Bacterial Wilt Disease and the Ralstonia Solanacearum Species Complex. pp. 145–157.

Lundvall, B.-Å., Johnson, B., 1994. The learning economy. J. Ind. Stud. 1, 23–42.

Maarleveld, M. and Dabgbégnon, C., 1999. Managing natural resources: a social learning perspective. *Agriculture and human values*, *16*(3), pp.267-280.

McDougall, C., Jiggins, J., Pandit, B.H., Thapa Magar Rana, S.K. and Leeuwis, C., 2013. Does adaptive collaborative forest governance affect poverty? Participatory action research in Nepal's community forests. *Society & Natural Resources*, *26*(11), pp.1235-1251.

Mekonen, S., Alemu, T., Kassa, B., Forbes, G., 2011. Evaluation of contact fungicide spray regimes for control of late blight (Phytophthora infestans) in southern Ethiopia using potato cultivars with different levels of host resistance. Trop. Plant Pathol. 36

Miller, J.S., Nolte, P., Olsen, N., Miller, T., Bohl, B., Thornton, M., 2006. Late Blight Management Action Plan for Potatoes. University of Idaho Extension.

Milinski, M., Sommerfeld, R.D., Krambeck, H.J., Reed, F.A. and Marotzke, J., 2008. The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proceedings of the National Academy of Sciences*, *105*(7), pp.2291-2294.

Mohajan, H.K., 2018. Qualitative research methodology in social sciences and related subjects. *Journal of Economic Development, Environment and People*, *7*(1), pp.23-48.

Nelson, R., Orrego, R., Ortiz, O., Tenorio, J., Mundt, C., Fredrix, M. and Vien, N.V., 2001. Working with resource-poor farmers to manage plant diseases. *Plant Disease*, *85*(7), pp.684-695.

Olanya, O. M., E. Adipala, J. J. Hakiza, J. C. Kedera, P. Ojiambo, J. M. Mukalazi, G. Forbes, and R. Nelson., 2001. Epidemiology and population dynamics of Phytophthora infestans in Sub-Saharan Africa: progress and constraints. *African Crop Science Journal*, *9*(1), 185-193.

Olanya, M., Nelson, R., Hakiza, J., Ewell, P., El-Bedewy, R., Kakuhenzire, R., Namanda, S., Kasheija, I., Wagoire, W., Ngombe, B. and Musoke, C., 2010. Comparative assessment of pest management practices in potato production at Farmer Field Schools. *Food Security*, *2*(4), pp.327-341.

Opdam, P., Coninx, I., Dewulf, A., Steingröver, E., Vos, C. and van der Wal, M., 2016. Does information on landscape benefits influence collective action in landscape governance?. *Current Opinion in Environmental Sustainability*, *18*, pp.107-114.

Orr, A., 2003. Integrated pest management for resource-poor African farmers: Is the emperor naked?. *World Development*, *31*(5), pp.831-845.

Ortiz, O., Nelson, R., Olanya, M., Thiele, G., Orrego, R., Pradel, W., Kakuhenzire, R., Woldegiorgis, G., Gabriel, J., Vallejo, J. and Xie, K., 2019. Human and technical dimensions of potato integrated pest management using farmer field schools: International Potato Center and partners' experience with potato late blight management. *Journal of Integrated Pest Management*, *10*(1), p.4.

Ostrom, E., 2012. Experiments combining communication with punishment options demonstrate how individuals can overcome social dilemmas. *Behavioral and Brain Sciences*, *35*(1), pp.33-34.

Parsa, S., Morse, S., Bonifacio, A., Chancellor, T.C., Condori, B., Crespo-Pérez, V., Hobbs, S.L., Kroschel, J., Ba, M.N., Rebaudo, F. and Sherwood, S.G., 2014. Obstacles to integrated pest management adoption in developing countries. *Proceedings of the National Academy of Sciences*, *111*(10), pp.3889-3894.

Pacilly, F.C., van Bueren, E.T.L., Groot, J.C. and Hofstede, G.J., 2019. Moving perceptions on potato late blight control: workshops with model-based scenarios. *Crop Protection*, *119*, pp.76-87.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D. and Taillieu, T., 2007. Social learning and water resources management. *Ecology and society*, *12*(2).

Pernezny, K., Elliott, M., Palmateer, A., Havranek, N., 2016. Guidelines for Identification and Management of Plant Disease Problems: Part II. Diagnosing Plant Diseases Caused by Fungi, Bacteria and Viruses. Plant Pathology Department, UF/IFAS Extension publication.

Petty, R.E. and Cacioppo, J.T., 1986. The elaboration likelihood model of persuasion. In *Communication and persuasion* (pp. 1-24). Springer, New York, NY.

Poteete, A.R. and Ostrom, E., 2008. Fifteen years of empirical research on collective action in natural resource management: struggling to build large-N databases based on qualitative research. *World Development*, *36*(1), pp.176-195.

Reason, P. and Bradbury, H. eds., 2001. *Handbook of action research: Participative inquiry and practice*. Sage.

Reed, M.S., Evely, A.C., Cundill, G., Fazey, I., Glass, J., Laing, A., Newig, J., Parrish, B., Prell, C., Raymond, C. and Stringer, L.C., 2010. What is social learning?. *Ecology and society*, *15*(4).

Reeves, T., Ohtsuki, H. and Fukui, S., 2017. Asymmetric public goods game cooperation through pest control. *Journal of theoretical biology*, *435*, pp.238-247.

Reuben, E. and Riedl, A., 2013. Enforcement of contribution norms in public good games with heterogeneous populations. *Games and Economic Behavior*, *77*(1), pp.122-137.

Rodenburg, J., Schut, M., Demont, M., Klerkx, L., Gbèhounou, G., Oude Lansink, A., Mourits, M., Rotteveel, T., Kayeke, J., van Ast, A. and Akanvou, L., 2015. Systems approaches to innovation in pest management: reflections and lessons learned from an integrated research program on parasitic weeds in rice. *International Journal of Pest Management*, *61*(4), pp.329-339.

Röling, N. and Leeuwis, C., 2001. Strange bedfellows: how knowledge systems became Longer and why they will never be Long. *Resonances and Dissonances in Development: Actors, Networks, and Cultural Repertoires. Royal Van Gorcum, Assen, The Netherlands*, pp.47-64.

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L.C., Raboanarielina, C.M., Adegbola, P.Y., van Ast, A. and Bastiaans, L., 2015. RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. *Agricultural Systems*, *132*, pp.1-11.

Scott, G. J., Labarta, R., & Suarez, V., 2013. Booms, busts, and emerging markets for potatoes in East and Central Africa 1961–2010. *Potato research*, *56*(3), 205-236.

Senge, P.M., 2006. The Fifth Discipline: The Art and Practice of the Learning Organization (Revised and Updated Edition). Doubleday, New York.

Six, B., Van Zimmeren, E., Popa, F. and Frison, C., 2015. Trust and social capital in the design and evolution of institutions for collective action. *International Journal of the Commons*, *9*(1).

Shove, E., Pantzar, M., Wason, M., 2012. The Dynamics of Social Practice: Everyday Life and How It Changes. Sage.

Smith, E.A., 2010. Communication and collective action: language and the evolution of human cooperation. *Evolution and Human Behavior*, *31*(4), pp.231-245.

Thiele G, Theisen K, Bonierbale M, Walker T., 2010. Targeting the poor and hungry with potato science. Potato J 37(3–4):75–86

Van de Fliert, E., Dilts, R. and Pontius, J., 2002. Farmer researcher teams, farmer field schools and community IPM: different platforms for different research and learning objectives. *Wheelbarrows full of frogs: Social learning in rural resource management*, pp.121-133.

van de Fliert, E., Dung, N.T., Henriksen, O. and Dalsgaard, J.P.T., 2007. From collectives to collective decision-making and action: Farmer field schools in Vietnam. *Journal of Agricultural Education and Extension*, *13*(3), pp.245-256.

Van de Fliert, E., A.R. Braun, R. Asmunati, Wiyanto and Y. Widodo (1997), One step back, two steps forward: sweet potato ICM development in Indonesia. In: *Local R&D: Institutionalizing Innovations in Rootcrop Agriculture*, 153-168. CIP-UPWARD, Los Banos.

Van der Plank, J.E., 2013. Plant Diseases: Epidemics and Control. Academic Press.

Van Mierlo, B. and Beers, P.J., 2020. Understanding and governing learning in sustainability transitions: A review. *Environmental Innovation and Societal Transitions* 34, 255-269.

Vasse, J., Danoun, S., Trigalet, A., Allen, C., Prior, P., Hayward, A., 2005. Microscopic Studies of Root Infection in Resistant Tomato Cultivar Hawaii7996, Bacterial Wilt Disease and the Ralstonia Solanacearum Species Complex. pp. 285–291.

Yuliar, Nion, Y.A., Toyota, K., 2015. Recent trends in control methods for bacterial wilt diseases caused by Ralstonia solanacearum. Microbes Environ. 30, 1–11.

Zhang, B., Li, C., De Silva, H., Bednarik, P. and Sigmund, K., 2014. The evolution of sanctioning institutions: an experimental approach to the social contract. *Experimental Economics*, *17*(2), pp.285-303.

2

Chapter 2

Diagnosis of management of bacterial wilt and late blight in potato in Ethiopia: A systems thinking perspective[1]

[1] Published as Damtew, E., Tafesse, S., Lie, R., Van Mierlo, B., Lemaga, B., Sharma, K., Struik, P.C. and Leeuwis, C.
Diagnosis of management of bacterial wilt and late blight in potato in Ethiopia: A systems thinking perspective. NJAS-Wageningen Journal of Life Sciences, 86, pp.12-24.

Abstract

Potato is one of the most important food crops for smallholder farmers in the Ethiopian highlands. Diseases, particularly bacterial wilt (caused by Ralstonia solanacearum) and late blight (caused by Phytophthora infestans), are among the major constraints of potato production, despite continuous efforts to control them. Bacterial wilt and late blight are complex problems with multiple technical and institutional features, involving multiple actors with different perceptions and understanding, not only of the problem but also of possible solutions. Appreciating such complexity, this study adopted a systems thinking perspective. It aimed to explore actors' understanding of the complex problem situation and its implication for the management of the diseases at a collective level. Using a multi-stakeholder workshop and in-depth interviews, a qualitative study was conducted with actors that are directly or indirectly involved in the management of the two diseases. Results showed that actors essentially overlooked key systemic problems in the management of the two diseases. This is mainly reflected in actors' tendency to give event-level responses, shift responsibilities and engage in a mutual blaming to the problem of bacterial wilt and late blight. Lack of a preventive disease management culture, limited recognition of interdependencies among activities of actors, power inequalities, and top-down and linear approaches in information and knowledge sharing are identified as key structural problems that are underrated by the actors. We contend that the most appropriate way forward towards the management of both diseases is designing and implementing management strategies that, on the one hand, are preventive of disease epidemics, and on the other hand, foster horizontal information sharing, learning and collective action among the local actors in the system. Digital platforms, particularly mobile-based technologies, can play a role in catalyzing new forms of information sharing, broader learning, and collaboration among farmers and local actors.

Keywords:
bacterial wilt, late blight, systems thinking, complex problems, disease management

Introduction

Potato is the fastest growing food crop in Sub-Saharan Africa with a substantial increase in total production in recent years. There is a similar trend in Ethiopia: the total area of land cropped with potato has considerably expanded from about 62,000 ha to 296,000 ha resulting in an increase in total yearly production from 500,000 Mg to about 3,700,000 Mg in 10 years (CSA, 2006; CSA, 2016). As the Ethiopian population grows rapidly, potato offers opportunities as one of the main food security crops (Haverkort et al., 2012). However, despite the increasing importance of potato production in Ethiopia, its productivity remains low with an average yield around 12.3 Mg/ha, an amount very low compared to the attainable yield of up to 50 Mg/ha under improved farmer management conditions using improved varieties (CSA, 2016; Baye and Gebremedhin, 2012). A number of studies (Tsedaley, 2014; Haverkort et al., 2012; Gorfu et al., 2012; Kassa, 2012) identified disease pressure, particularly bacterial wilt and late blight[1], as the most important production constraint and the number one priority for farmers in the management of their potato crop. Bacterial wilt has spread geographically from few potato growing areas in the lowlands and medium altitudes to almost all potato growing areas since it was first reported in Ethiopia in 1956. Bacterial wilt is categorized as seed, soil, and waterborne. Because host resistance to bacterial wilt is limited, it is very difficult to control Kirk and Wharton, 2014; Burke, 2017). Late blight is known to occur throughout the major potato production areas in the country (Stewart, 1956; Gorfu et al., 2012; Mekonen et al., 2011). Late blight is primarily air-borne whereby the pathogen is carried over by wind currents or rain splashes to other plants/fields, but it is also seed-borne and soil-borne.. Although there are two growing seasons (*Belg and Meher*) in most potato growing areas in the country, potato is mainly grown in the short rainy season (*Belg*) that falls between February and May. A high disease pressure in the long rainy season is the main reason why *Belg* production is dominant, despite a high yield potential of the long rainy season (Haverkort et al., 2012; Garuma et al., 2012; Bekele and Eshetu, 2008).

Cognizant of the situation, a number of previous and on-going research and development efforts have been made by different governmental and non-governmental organizations to deal with the problem of late blight. The National Potato Improvement Program within the Ethiopian Institute of Agricultural Research (EIAR), together with the International Potato Center (CIP), several regional research Institutes and Ethiopian universities, has worked over the last three decades to develop potato varieties with resistance to late blight (Baye and Gebremedhin, 2012; Mekonen et al., 2011). On the other hand, bacterial wilt management has not received much attention (Gorfu et al., 2012), although there has been some research effort on areas of race characterization,

1 We couldn't find studies that tried to quantify total yield loss resulting from bacterial wilt or late blight disease in Ethiopia.

and screening of cultural and biological control methods (Abdurahman et al., 2017; Kassa, 2016; Kuarabachew et al., 2007; Lemaga et al., 2005). As part of a wider government-led 'Quality Declared Seed' program, there are recent attempts to manage bacterial wilt through a combination of technical and institutional arrangements (MoANR, 2013; Thiele et al., 2011). Despite these efforts, the overall success to date has been limited and both diseases still continue to be major challenges in potato production in the country.

Previous research on potato disease management in general, and management of bacterial wilt and late blight in particular, is notably dominated by technical aspects of the diseases. Most technical research areas covered a range of aspects, from pathogen distribution and genetic diversity to disease management practices such as host resistance, clean seed, chemical control and agronomic practices (Tsedaley, 2014; Kassa, 2012; Mekonen et al., 2011; Bekele et al., 2012; Lemessa and Zeller, 2007; Kassa and Beyene, 2001). Only few studies tried to take a wider perspective at farmers' level (MoANR, 2013; Gorfu et al., 2012) or at system level (Tadesse et al., 2017a,b; Gildemacher et al., 2009) to assess what formal or informal institutions exist and how the institutions operate in potato disease management in general, and bacterial wilt and late blight in particular. However, there is a very little attempt made to understand structural problems that give deeper insights on *why* such institutions (both formal and informal) or actors in it are operating the way they do and what that means to the management of late blight and bacterial wilt.

Plant disease results from complex interactions among biotic and abiotic factors including hosts, pathogens and environments, and farm level human activities that intentionally or unintentionally modify these interactions (Burdon et al., 2014; Franc, 1998). A good understanding of the disease cycle, including climatic and other environmental factors that influence the cycle, and cultural requirements of the host plant, are essential to design or implement an effective disease management strategy (Trabucco et al., 2013). Likewise, successful disease diagnosis or management approaches require networks of actors from the government, scientific institutions and local organizations which help to integrate surveillance and monitoring activities on the different dynamics of the disease (Kelly et al., 2017; Mazet et al., 2014). For instance, the risk of late blight can be reduced if growers communicate with relevant parties, such as neighbors, buyers, and extension workers when late blight infects their farms. Such practice can be realized when the different actors, who are supposed to have a vested interest in the management of the bacterial wilt and late blight, find a way to network and coordinate their efforts (Liao et al., 2016). This is in line with the notion of 'connective action' which is described as a new way of organizing collective action networks (Bennett and Segerberg, 2012). In this regard, various forms of ICTs (Information and Communication Technologies) may catalyze new forms of network formation, information exchange and learning that are relevant to address coordination problems (Kelly et al., 2017; Bennett and Segerberg, 2012). ICTs can play a role in facilitating real-time monitoring, cross-level and cross-scale information sharing, engagement and interaction between individuals, organizations, and agencies at multiple governance levels (Karpouzoglou et al., 2016). However, as highlighted in different strands of literature, catalyzing new forms of collective action transcends the discussion on the potential of various technology platforms and requires the articulation of the role of social, institutional or political landscapes which are crucial in formulating collective action frames (Bennett and Segerberg, 2012; Karpouzoglou et al., 2016; Chapman and Slaymaker, 2002)..

In our problem context, there are different actors like farmers, researchers, government decision makers, NGOs, crop inspectors, business owners, and information providers who are expected to have different understanding or perceptions regarding the problem situation and the potential solutions to their perceived problem situation. Such different understanding and perceptions about the problem situation and the potential solutions are expected to shape the behavior of different actors towards organizing their actions in the management of the two diseases Maloy, 2005; Leeuwis and Aarts, 2011; Jørgensen et al., 2009; Aarts and van Woerkum, 2005; Checkland, 2000). As highlighted in Cieslik et al., [2018] collective action problems are further deepened by power imbalances and imperfect or asymmetric information. This warrants the need for a nuanced look at existing perceptions, views and practices that in one way or another play a role in shaping collective action in the management of the two diseases. A good understanding of this complexity is, therefore, a critical step to unravel whether and how ICT enabled collective action can play a role in the management of bacterial wilt and late blight.

In the context of disease management, traditional silo approaches (segmenting a complex whole) usually serve as barriers to understand underlying problems that emerge out of complex interactions (Mazet et al., 2014). In this regard, 'soft systems thinking', provides a framework for a holistic appreciation of complex problem situations by eluding fractionalization of problems into pieces. Moreover, the soft systems perspective provides enough emphasis to fluid and intangible social aspects that are known to slip under the radar of 'hard systems thinking' approach (Checkland, 2000; Senge, 2006). We posit that actors involved in the management of bacterial wilt and late blight need to have an understanding of systemic problems to be able to collectively design and implement effective management strategies. We define 'systems thinking' as actors' understanding of the systemic structure or underlying patterns of behavior in a complex problem situation of bacterial wilt and late blight management. Although there are technical and socio-ecological differences between the two diseases, at systemic level problems of both diseases share more or less similar organizational actors and institutional context. Owing to this, our study mainly takes into account differences that are believed to influence how the different actors understand the problem situation in the management of the two diseases. Adapting concepts from soft systems thinking, this article will answer the following three research questions: 1) To what extent and how do actors understand the systemic structure in the complex problem of management of bacterial wilt and late blight? 2) How does their understanding of the systemic structure facilitate or hinder collective action in the management of bacterial wilt and late blight? and 3) What opportunities exist for ICTs in overcoming collective action problems?

The research was conducted in Ethiopia and specifically addressed farmers in Wolmera and Gumar districts. Data were collected in a multi-stakeholder workshop and through in-depth interviews with direct and indirect actors[2]. The interviews generated qualitative information about actors' understanding of the problem situation in relation to our area of inquiry outlined in the research questions.

The article is structured as follows. The next section presents our conceptual framework by first briefly addressing 'systems' and the prominent distinctions in 'systems thinking' at a theoretical level. The subsequent section then explains the methodology that was used to collect and analyze the data. This is followed by the results section and the discussion section. The article ends with presenting the main conclusions.

Conceptual framework

Unlike the hard tradition which presumes that the world contains 'systems' which can be engineered, the soft tradition assumes a 'system' to be a fluid social world, one which persists and changes (Checkland, 2000; Vickers, 2013). In this regard, systems or 'human activity systems' do not pretend to be models of the world with predefined elements but mainly a set of interlinked activities that embody a particular purpose or a specific stated way of viewing the world (Checkland, 2000; Mingers, 1980). Appreciating such system construct, Senge (2006) defines 'systems thinking' as a mental model for seeing the structures that underlie complex situations and for selecting high from low leverage change. Thinking in systems is about reframing how people think about what they view as a problem in the first place, and what solutions might look like (Cabrera et al., 2008). Checkland (2000) refers this framing of a complex problem situation as a perspective of a reality or 'a world-view'.

Conceptual literature in the field of plant disease management emphasizes two key elements when discussing disease management. One is the use of systematic approaches to diagnose diseases and monitor risk levels. The second one is selection and implementation of short-term or long-term disease management strategies (Pernezny et al., 2016; Van der Plank, 2013; Apple, 1977). Taking these elements as major activities in disease management, we consider bacterial wilt and late blight management as a complex 'human activity system' that involves a range of interlinked activities. However, as highlighted in the introduction, complex problem situations involving human affairs are not straightforward and cannot be fully defined in technical terms. Understanding of the

2 Those actors with first-hand involvement in the potato disease management are labelled as direct actors. Actors which do not directly work in the sector but obliquely influence the wider context are categorised as indirect actors.

wider institutional context is equally important (Checkland, 2000; Midgley, 2003). In soft systems thinking, institutions are not just simple administrative and political organizations, but also are the rules, norms or perceptions which structure and are structured by people's practices and their areas of social endeavor (Krueger and Gibbs, 2010; Röling and Leeuwis, 2001a). These institutions, therefore, can be 'formal institutions' which are consciously designed and clearly specified as in the form of written laws, rules or regulations, within which different social entities or actors operate, or, can be 'informal institutions' such as political culture, unwritten customs, norms or perception which informally shape the way 'business is done' by different actors (Krueger and Gibbs, 2010; Smith, 1997). This perspective framed our approach to a complex problem situation whereby different thematic lines through the lenses of 'technical' and 'institutional' problem dimensions are used to analyze actors' understanding of systemic structure in the problem of bacterial wilt and late blight management. Our conceptualization of systems thinking that is employed to discuss the thematic lines is elaborated in the next paragraph.

In complex and dynamic human systems, Senge (2006) positions systems thinking as a conceptual cornerstone and a fundamental discipline that frames how actors ('learning organizations' as he calls them) understand a complex problem situation and in turn respond to it. Systems thinking is about actors' understanding of systemic structure that defines a system's pattern of behavior to create the conditions for events to become likely. It entails going beyond individual mistakes, personalities, organizations or snapshots of events to see underlying patterns in the system. Seeing major interrelationships underlying a problem situation leads to new insights into what might be done to change the pattern of behavior which in turn can change events. Based on this notion, one way of investigating if people see systemic structure or underlying patterns is to look into the way situations are explained by them. In this respect, the explanation can be a reactive one based on events that usually leads to practicing superficial or symptomatic solutions ('shifting the burden' as Senge (2006) calls it) that may only improve events temporarily but leave the underlying problem unaddressed or even worsened. The other type of explanation, not common but very powerful, is a generative one based on systemic structure or root causes to a complex problem situation which helps in identifying and applying fundamental solutions to a problem situation. Having such systemic orientation also reduces the tendency of actors to victimize or blame a particular group or organization as a cause of a problem situation (Senge, 2006). Such perspective guided our analysis of actors' understanding of systemic structure in the complex problem situation of bacterial wilt and late blight management.

To clearly discern what is and is not an evidence of "systemic structure understanding", we made an extension of the concept by defining different instances for two types of explanations and associated practices (systemic structure vs event level) discussed in the conceptual framework. This is addressed in Table 1.

Table 1: Event-level and structural explanations and actions.

1. Event-level explanations and actions	2. Structural explanations and actions
a. If actors talk about personal, organizational or event related problems when explaining the different aspects of the problem situation framed as technical and institutional	a. If actors talk about long-term patterns and interactions among different activities when explaining different aspects of the problem situation framed as technical and institutional
b. If actors explain or practice solutions that are targeted at fixing personal, organizational, event-level problems	b. If actors see interdependency between their activities or engage in concerted action to deal with perceived problems
c. If actors take assumption of an 'external cause' to a problem or blame others for a problem situation	c. If actors see their actions affect the behavior of other actors to create the problem situation they discuss
d. If actors mainly focus on their own decisions or dwell on their own judgment about 'actions to improve' a problem situation	d. If actors talk about the need for accommodations of different perspectives and interest of actors

Materials and methods

Study context and actors involved

The study was conducted based on data generated from different actors that are involved in the management of potato bacterial wilt and late blight in Ethiopia. CIP (International Potato Center) researchers and secondary literature were consulted to decide on participating actors, both in a workshop and in in-depth interviews that were employed to collect our data (Haverkort et al., 2012; Gildemacher et al., 2009; Hirpa et al., 2010). Based on this, seven categories of actors were included in the study: Government actors, Non-government actors, FBOs (Farmer-based organizations), Research and Training Institutes, Farmers, ICT-based agricultural information providers and Private sector actors. Based on the information from the workshop, the government (Ministry, Regional, Zonal, District and Kebele agriculture offices) plays an important role in agricultural policy and strategy formulation, public extension service provision. They also work, almost single-handedly, in agricultural inputs and outputs quality control and certification, and in input and output market through farmer cooperatives and unions. Research and training institutes are mainly involved in the development, adaptation, demonstration, and popularization of agricultural technologies and in training of subject matter specialists. They also have a role in pest/disease inspection of imported potato germplasms or samples collected from potato fields and in providing technical advice in the development of strategies in input use, disease diagnosis, and management. Actors that are involved in the provision of agricultural information use different platforms (mobile-based interactive voice response; community radio and videos) to reach out to their target communities. Only ATA (Agricultural Transformation Agency) provides information on potato agronomy and disease management through its mobile-based interactive voice response (IVR) system in pilot districts, not including our study districts. NGOs are involved in training and capacity development, agricultural inputs service, market linkages and extension services. FBOs, with strong monitoring from the government, principally work in seed potato production and agricultural input-output markets. The cooperatives have management committees, which are usually composed of model farmers, to monitor potato disease problems among others. Due to the active involvement of the government in input and output markets mainly through farmer cooperatives, the private sector was found to have quite limited engagement, at least in relation to activities relevant to the management of the two diseases. This is evident in Table 2 where it shows that it was only possible to include a single private sector actor both in the workshop and interviews. Administratively, the actors are distributed from the national (federal) level to 'Kebele' level, the smallest formal administrative unit, and are situated in the capital and regional cities and in zonal and district towns in different parts of the country.

As one actor category, individual farmers were included from Wolmera and Gumer districts which are among the major potato growing districts in the country. Wolmera is located in the Oromia region, at about 40 km west of Addis Ababa while Gumer is in the Gurage zone of the SNNP region at 220 km southwest of the capital city. Both districts are in the cool highlands with potato being one of the most important crops grown in a predominantly smallholder farming system.

Data generation methods

Multi-stakeholder workshop

In early November 2016, a one-day multi-stakeholder workshop was organized with 21 participants representing the above-stated actor categories. The workshop was organized with the objective of joint identification of systemic constraints and entry points for intervention in the management of late blight and bacterial wilt. A methodology from the Rapid Appraisal of Agricultural Innovation System (RAAIS) was adopted to systematically engage participants in a series of sessions to generate preliminary information on perceived constraints and opportunities in the management of the two diseases. Based on experience from RAAIS studies in different African countries the workshops provided a fast-track approach to have a generic understanding of the system that was subsequently validated and explored in more detail using the in-depth interviews (Schut et al., 2015). More generic but key findings emerged from the workshop session (e.g. *linear thinking, limited recognition of interdependency and shifting responsibilities*). Findings of the workshop were also instrumental in shaping the conceptual and methodological direction of the research. The workshop sessions were facilitated by the researchers and all workshop session presentations were audio-taped and transcribed.

In-depth interviews

Informed by the operational definitions outlined in the conceptual framework, a set of discussion points were developed. Between April and June 2017, in-depth interviews were conducted in a dialogue-based style with 30 individuals from the different actor categories out of whom 27 interviewees consented and were audio recorded. The decision on the optimal number of interviews was based on the concept of 'saturation' or the point at which no new information or themes were observed in the interview data (Guest et al., 2006).

All the interviews were conducted by the researchers with each interview taking one and half hours on average. During farmer interviews, district experts and extension workers were used as facilitators and, in some cases, as translators. As much as the formal interviews, informal conversations were instrumental in capturing information on issues that are perceived as socially or politically sensitive by the informants. Transect walks in farmers' potato fields and visits to agricultural offices, cooperative unions, input market dealers, seed quality inspection laboratories and research facilities of research centers helped get a picture of the situation on the ground. Field notes and photographs were also taken during the visits. Secondary literature was reviewed to identify some relevant teams under formal and informal institutions (Seed quality control, Research and extension, and Information sharing culture) that were found to be relevant in our problem context (Haverkort et al., 2012; Gildemacher et al., 2009; Trabucco et al., 2013; Liao et al., 2016; Guest et al., 2006). Table 2 presents an overview of the data generation methods used with the various actors at the different administrative levels.

Table 2: Summary of data generation method.

Data generation method	Objective	Administrative level	Actor categories and number of participants							
			Farmers	Govt. actors	Research and Training Institutes	NGOs	Agricultural Information providers	Private sector	FBOs	Total
Multi-stakeholder workshop	Participatory analysis of systemic constraints in potato bacterial wilt and late blight management	National	-	1	2	2	3	-	-	**21**
		Regional	-	1	1	-	-	1	0	
		District	-	1	-	-	-	-	2	
		Kebele	4	-	-	-	-	-	3	
In-depth interview	Generate information on actors' views of bacterial wilt and late blight problem situation	National	-	2	3	2	3	-	-	**30**
		Regional	-	2	3	-	-	1	-	
		District	-	4	-	-	-	-	2	
		Kebele	6	2	-	-	-	-	-	

Data analysis

The discussion points used for the interviews were loosely organized to allow actors to share their views and practices on a range of technical and institutional thematic lines that emanated from our conceptual framework (Disease monitoring and risk assessment, Disease management strategy and Politics and power relations) and that were identified from secondary literature (Seed quality control, Research and extension, and Information sharing culture). Discussion topics mainly focused on:

1. Actors' perception of their roles in relation to potato disease management; their views about major problems in potato disease management; the solution they propose or the actions they take to deal with the perceived problems; the challenges they face in the process of implementing the solutions

2. Actors' views about the roles of other actors, the nature of their interactions and the challenges they encounter when working with other actors; their views on how to deal with such challenges

3. Actors' planning and implementation processes of different activities they execute; if and how they involve other actors in this process; their views and encounters on conflicting interests and the way they are handled

Based on our conceptualization of actors' understanding of a complex problem situations (second element of conceptual framework), views and practices of actors that were captured in the discussion were coded and categorized into the different technical and institutional thematic lines. Inferences were then taken from their utterances in light of the operational definitions given on what constitutes and does not constitute a systemic understanding. Secondary data analysis was used to support our expert interpretation of the results and to put it in the context of current knowledge.

Results

The Results section is presented along the following three problem dimensions: Technical issues, Formal institutions and Informal institutions. As indicated in the Conceptual framework and Methodology sections, different themes are used to discuss the findings under each problem dimension. Themes discussed under the technical dimension are 'Disease diagnosis and risk monitoring' and 'Disease management strategies'. Under formal institutions 'Seed quality control' and 'Research and extension' are two thematic lines discussed. 'Political culture and power relations' and 'Information sharing culture' are themes discussed under informal institutions. Each section specifically addresses actors' understanding of the dimensions.

Actors' understanding of the technical problem aspects of management of bacterial wilt and late blight

Disease diagnosis and risk monitoring

High-level experts in the government, research centers and NGOs felt that disease diagnosis or risk assessment on the incidence or epidemics of bacterial wilt or late blight should be principally done by government extension workers and farmers themselves. In this regard, most informant actors, particularly government experts and researchers, strongly believed that apart from resource constraints to effectively respond to the diseases, limited knowledge of extension workers and farmers on the symptoms, favoring conditions and dispersion mechanisms of the two diseases is the key problem for existing gaps in diagnosis and monitoring of the two diseases. When it comes to technical advice on late blight and bacterial wilt management farmers seem to prefer to rely on their own judgment. Although extension workers thought that farmers have limited knowledge on detecting the diseases, most interviewed farmers believed that it is not necessary to seek advice on detecting the two diseases. Detecting late blight was perceived as an easier task for the farmers that can be done without help from the extension workers. A farmer said: *"When you see a disease symptom on your field, you just buy chemical and apply".* Farmers also seemed to be reluctant to seek advice on bacterial wilt[3] monitoring. A farmer stated: "*There is not much the extension workers could do for you, there is no remedy for the disease*".

At the Ministry, and regional levels, crop protection experts understood their mandate as strategic planners and resource mobilizers in the management of different migratory and regular crop insects and diseases. There are other more economically important crop diseases that are given more attention than potato diseases. Experts gave a strong emphasis on insects and diseases of crops that are designated as strategic by the government. These are crops such as wheat, teff, maize, barley, oilseed and pulses that are produced in a larger amount, cover a wider geographic area or are essentially export commodities. Among the insects and diseases that are given high emphasis, Desert locust, Armyworm, rust, and maize lethal necrosis disease are the major ones. Owing to the focus on other crops, crop protection experts at the Ministry and regional offices said that they had little information on potato diseases in general and late blight and bacterial wilt in particular. In this regard, some opinions of district experts and extension workers at the study sites supported what is observed at the Ministry and regional levels. A district expert in Wolmera stated: *"Being one of the most important crops in our district, potato production is highly constrained by late blight and bacterial wilt but as the crop is given little attention at the regional level, it is affecting our district."*

3 Almost all extension workers and farmers find it difficult to mention symptoms or spread mechanisms for bacterial wilt.

Ministry and regional experts stressed the importance of getting their personnel and logistics ready before seasonal insect and disease outbreak comes. Once they have the resources at their disposal they can coordinate their efforts with all crop protection experts working at different levels and go out for a campaign until the disease or pest is under control. Time-bound responses are given when there is a high incidence or outbreak of diseases. But the main challenge for the high-level experts is their limited capacity to timely respond to disease outbreaks. Experts complained: "*we usually try to control outbreaks after disease or pest has already inflicted too much damage*". Farmers also seemed to follow the same routine whereby they responded after the incidence of diseases. This was highlighted by a farmer in Gumer who said: "*to reduce damage, many farmers apply chemicals when late blight is observed.*" The monitoring and gathering of information on disease incidence or severity levels are mainly done by the government, an activity that is perceived as poorly organized by experts in the Ministry and regional agricultural offices. Only farmers or field level government experts do the diagnosis and share the information with high-level experts at the Ministry and regional agricultural offices. Information on high incidence of late blight is shared with regional agricultural offices who are supposed to coordinate management responses but there is no similar practice for bacterial wilt so far. The contribution of the national research institute through its crop protection research unit is marginal due to researchers' perceived logistical and human resource problems. It is worthwhile to mention that neither the extension workers nor an informant seed quality inspector operating in Gumer district were aware that the cooperative union has experts working on disease inspection, and similarly a district crop protection expert had no information on the existence of the seed quality inspection office.

Disease management strategies

Most farmers believed that the only available management option for late blight is fungicide application, which they usually apply after disease occurrence. Few farmers mentioned that resistant potato varieties such as Gudene and Belete are better resistant to late blight compared to their local varieties. But they tended to relate the importance of the resistant varieties rather to their contribution to increased productivity than to their ability to resist late blight, which was contrary to researchers' view that the primary objective of releasing the varieties is for late blight resistance. Farmers seemed to be convinced that bacterial wilt management is beyond their capacity and that the local experts have failed to 'bring them solutions'. Similarly, there was a shared view among government experts that management of late blight can be done with existing fungicides, for which they facilitate access through farmer cooperatives. Shifting potato production to the short rain season was also mentioned by workshop participants as another key strategy to deal with late blight. Interviews revealed that in Gumer about 90% of the total yearly potato production is produced in the short rain season where late blight stress is mild. Bacterial wilt management is something that is difficult for the district experts to explain. Wolmera district expert articulated: *"late blight can be controlled with fungicide but bacterial wilt is a complicated disease and is beyond our capacity, I am personally tired of being unresponsive to farmers' consistent complaint"*. The only 'curative' management option that extension agents advise farmers for bacterial wilt is 'roguing' of wilted plants, which farmers label as hardly effective.

Researchers tended to associate the problem of late blight with farmers' limited access to late blight resistant varieties that have been released by the research centers. They also listed bacterial wilt management recommendations[4] that are barely known to potato growers and extension workers participating in the study. A researcher shared his view: *"our many experimental studies have proved that using resistant varieties is key to deal with late blight"*. Researchers mentioned resistant cultivar selection process as the most important technical aspect of late blight management arguing that releasing a disease resistant variety is a lengthy and demanding process that takes as long as twelve years from acquiring germplasm[5] to screening and performance evaluation which they thought is an overwhelming task.

Actors' understanding of the institutional problem aspect of management of bacterial wilt and late blight

The existence of laws, operational guidelines and procedures in 'Seed quality control' and clearly specified approaches in 'Research and extension' services (e.g. Participatory Research and Extension, non-pluralistic extension approach etc.) form the basis for their categorization as formal institutions. However, such formal institutions were not in isolation and interplay with existing informal institutions and the different technical problem aspects of the diseases discussed in the previous section.

Seed quality control

For workshop participants, marginal implementation of different seed quality-related laws and regulations[6] due to the government's limited enforcement capacity was taken as a major challenge in potato disease management. Seed proclamation and legal framework on variety release, registration and internal quality control (Seed Proclamation No. 782/2013), the Seed System Development Strategy (UNDP, 2011), and the Quality

4 Keeping farm equipment clean, roguing out and burying of infected plants, sorting infected tubers, eliminating host weeds, crop rotation, using clean irrigation water are among the practices.

5 CIP is a key partner in germplasm importation from countries like Peru, Kenya and Uganda.

6 Although there is no specific organization responsible for quality control of seed potato, in the last few years different seed quality related laws, strategies and guidelines that apply to potato and other crops have been developed.

Declared Seed program (ESA, 2015) were considered as the major ones. As can be seen from the documents and based on the opinion of government representatives from the workshop, MoANR (Ministry of Agriculture and Natural resources) consulted and worked with different partner organizations in developing the strategies. But there seemed to be a shared view among many of the workshop participants that its implementation should have been realized by the government seed quality control and regulatory offices at regional levels. In this regard, interviewed experts at the government regulatory offices also strongly felt that such regulations or procedures have not been effectively applied. A serious shortage of inspectors and logistical constraints to cover a wide geographic area under their mandate are among the main problems mentioned affecting their inspection capacity. In the QDS (Quality Declared Seed) scheme there is, at least in principle, 'zero tolerance' for bacterial wilt for seed potato growers. The inspectors assert that when a breach of the laws and procedures is observed, they try to take timely corrective measures as stipulated in the laws. The penalty ranges from giving written warnings and banning the sale of the seed potato to revocation of licenses. Apart from the inspection that the experts do, seed-producing cooperatives have farmer committees that inspect and supervise seed potato fields of members for disease problems. In this regard, government inspectors constantly blame the committees for their poor capacity, which according to them, has pushed all the inspection burden on them. Farmers and committee members criticize back inspectors for not doing a timely inspection as it is impossible for them to sell their seed without getting the approval of the inspectors.

NGOs that have active involvement in seed potato exchange are well aware of existing gaps in seed quality control. They explain that such problem is out of their mandate and that the government should have dealt with. When there is an appeal from the government during times of crisis, the NGOs involve in emergency seed provision programs whereby they buy seed potatoes from different seed potato producing cooperatives in the country including farmer cooperatives in the study districts. They contend that their practice is 'safe' as they are buying seed from cooperatives that are government-certified, and further argue that the government's priority in times of crisis is to curb emergency situations.

Research and Extension

Researchers in the workshop claimed that since the introduction of a participatory research approach in the national research system, their success in transferring knowledge and promoting agricultural technologies has relatively improved. Although in principle the participatory approach is meant to be implemented in close collaboration with the public-funded extension service and other relevant actors[7], interviewed researchers felt

7 The Research, Extension and Farmer Linkage Advisory Council (REFLAC), group of stakeholders beyond research, extension and farmers, is meant to lead the linkage between research and extension but with marginal success so far [18].

that joint engagement is still poor mainly due to the limited support they get from the public extension system. A researcher explained: *"Extension workers are supposed to closely follow up the research activities especially in our absence but as the local administration hardly see the activities as their own, extension workers have limited awareness and show little interest in the research activities. In many cases, we are obliged to pay per-diems to bring the extension workers on board and hire guards to avoid theft from farmers in the experimental fields".* Another researcher added: "*all the delicate research processes done on experimental fields is considered as a waste of time by many of the low-level experts*". District experts and extension workers acknowledged the weak collaboration with the research but held researchers' approach responsible for the situation. According to them, they usually have little information on the objectives of the research activities as the researchers do not fully involve them in the process. A district expert contended: *"It is common to see research experiments in our area that we have no knowledge of how it is initiated"*.

Limited knowledge of lower level experts on crop-specific problems like bacterial wilt and late blight was among the pressing problems mentioned by the researchers that are hampering technology adoption. Another critical challenge for researchers was a scarcity of pathologists in the research system, a similar concern that was also raised by regional seed quality inspection offices. For them, universities are not giving enough attention to the problem. Interestingly, an interviewed plant pathology professor in a university, who had no knowledge of the researchers' and the inspectors' claim, shared a different view: "*No university in the country trains students in pathology at the bachelor level, I see no need! We used to train pathologists at master's degree level but as there is no job for them, we decided to shift the program to a more generic discipline in crop protection*".

Researchers largely see their roles as technology or knowledge generators. A researcher affirmed: "*we have a clear mandate in the system which is generating appropriate technology*". Informant researchers considered the public extension[8] as the weak link between their technologies and farmers. There are research departments with names like "Technology Transfer and Commercialization Directorate", "Technology Transfer Coordination Unit", and have research positions as "Technology transfer research officer". For the researchers 'the extension research' wing in the national research system has been playing an important role in facilitating conditions for technology adoption by demonstrating, promoting and popularizing different technologies generated in the research centers. However, to their dismay, a recent BPR (Business Process Reengineering) reform[9] in SARI (South Agricultural

8 Researchers claim that apart from knowledge gaps of extension workers in crop protection, spending their time in other activities, such as distribution of agricultural inputs, and collection of input credits and taxes from farmers, is negatively affecting their role as technology promotors.

9 After recognizing the gap in 'bridging' research and extension, the extension research department is now back in the structure again.

Research Institute) disbanded the extension research department with a narrative that existing role of the department is something that can be covered by the technology developers themselves.

Actors' understanding of informal institutional problem aspect of management of bacterial wilt and late blight

Political culture and power relations

The government actors, particularly at the Ministry and regional level, expressed the belief that they played a key role and had a wide range of activities from policy and strategy formulation to resource mobilization and implementation of strategic plans. The Ministry of Agriculture and Natural Resources was considered by many of the actors as a focal office at the top of the structure with the highest authorized decision-making body. Country-wide strategic and annual plans have been developed by different departments at the Ministry and regional levels to go down until it reaches the lowest administrative unit (Kebele)[10]. Decision makers and experts at the Ministry and regional levels argued that doing strategic planning and monitoring at the high level is instrumental to coordinate countrywide agricultural development activities. Some district experts also claimed that the centralized planning process facilitates effective communication with farmers. Experts at the study districts mainly talked about the benefit potato farmers would get if they strictly follow experts' advice whether in the management of bacterial wilt or late blight or in other agricultural activities. Although many of the lower level experts reflected this view when it came to their downward relationship with farmers, they were also found to have reservations on their upward relationship with high-level experts and decision makers at the regional and ministry level. A seed quality inspector uttered: "*the regional office sends us the number of hectares of seed potato field that we are supposed to inspect in a year. We can only send feedback if it is not workable. Sometimes they send us numbers that are much higher or lower than what is planted in a season*".

Researchers distinguished the Ministry as a powerhouse that decides on the fate of agriculture in which researchers have little voice. A metaphoric description of the situation by a researcher was: "*Our research institute is a teeth-less lion, there is not much we can do about the problem of bacterial wilt and late blight*". The NGOs and the agricultural information providers also stressed the importance of having development projects that are in line, or at least not in contradiction, with government interests to be able to sustain in the system. An NGO expert illustrated a situation: "*Our new project approach on*

10 The plan can cascade down to the level of individual farm households as is the case in one of the study districts, Gumer. The 'politics and power relation' section provides a more detailed illustration of the planning process.

organic potato farming and biological disease control has been an issue for the government. If we implement our project, it means that about five hundred seed potato producing farmers that will participate in our project are not going to use inorganic fertilizers, chemicals or other inputs that are government recommendations. This became a huge concern for the government people. You know, one has to be cautious in matters like this as the government views us (NGOs) only as 'gap-fillers' and can tell us to go away at any time".

Almost all actors from the workshop or the interviews acknowledged that farmers are their key partners. However, many experts from the different actor categories, particularly government experts at the lower level, held the view that despite their efforts, farmers' 'lack of knowledge' was a major challenge for the sustained problem of bacterial wilt and late blight. Likewise, NGO experts and agro-input suppliers also complained how 'limited awareness of farmers' and 'resistance to change' have compromised the success of their interventions or services. Although many of the interviewed experts believed that trainings can eventually change farmers' situation, they also mentioned that farmers usually show little interest to 'attend' or 'learn' from the trainings they organize. Among all the actors, the potato farmers are the most reluctant to share their views and mostly shy away from discussing matters that they perceive as political or will offend other actors. Very common utterances from farmers when they talked about their engagement with other actors included: "*…the district and CIP works for us….*"; "*based on the directive given to us….*"; "*…just like they told us….*"; "*if they bring us a solution…*"

The case box portrays a picture of the government power structure through which different agriculture-related plans are channeled. In such arrangement, farmers are expected, at least in principle, to comply with a plan that emanates from the government's strategic development agenda.

Case Box: *Based on countrywide strategic plans such as GTP (Growth and Transformation Plan), AGP (Agricultural Growth Program), SLM (Sustainable Land Management), short-term plans are developed by high-level experts in the different departments of the Federal Ministry or regional agricultural offices. Plans developed at this level will be shared with each zonal agricultural office within the regions. Based on those figures, the zonal offices disaggregate the information to each district under the zone and the district follows the same procedure to distribute it to the 'Kebeles' which are the lowest formal government administrative levels in the country. In such a cascade of plans, the role of the offices at immediate lower level is more of providing feedback on invalid assumptions. Although it is not formally part of the government administrative structure, a 'Kebele' also called 'Peasant Association' in rural Ethiopia, is divided into clusters that contain quite a few groups of farmers that are labeled as 'Farmer Development Groups'; the number of farmers in each group ranges from twenty-five to forty. In an ideal situation, three extension workers are distributed to closely work with such groups. Each development group has leaders appointed as chairman, vice chairman and secretary who, in most cases, are 'model farmers' and have a strong link with the local administration. To be able to get to individual farmers, 'Farmer Development Groups' are divided into a group of five farmers which is locally known as 'and le asmest', meaning 'One-to-Five'. In this final social grouping, as its name indicates, one (Model) farmer leads a team of five farmers. Using this structure, which has been in place for a decade or so, the government tries to structure its power and communicates its development agenda until it gets to a farm household level. The 'Kebeles' have a standardized form that will be filled by each household which in aggregate will fit into its Kebele-wide plan.*

Information sharing culture

Lower level government experts at the districts mainly use the social organization, discussed in the 'Politics and Power relations' section, to share different types of information with farmers. They said that through the structure, they can easily share information with farmers on different development agendas including agriculture. In such communication, mobile phone plays an important role according to a district agriculture office head in Gumer. He illustrated: *"These days, communicating farmers has become easy. All we have to do is call leaders of each 'Farmer Development Groups' and pass our message and the leaders will then call and tell each 'one-to-five' leader under them. The 'one-to-five' leaders can easily reach out the rest of the four farmers in their group who usually are their neighbors"*. In such a way model farmers (group leaders), assisted by the extension workers, are expected to play a key role in facilitating information sharing with farmers. The experts labeled the model farmers as fast adopters and innovators who can play an important role in influencing other farmers that are perceived to be slow in taking up technologies. A district expert explained: *"We have model, middle and laggard farmers. We focus on model farmers who are only about ten percent of the farmers"*. Government initiated trainings are organized separately to the model farmers and then together with the rest of the farmers to help the models play their catalyst role effectively. However, some of the informant farmers seemed to have their reservations on the approach stating that model farmers are usually reluctant to share the information they access and are only benefiting themselves.

Organizations that are engaged in providing agriculture-related information to farmers and other actors through the use of different ICT platforms mainly see the problem of bacterial wilt and late blight and other crop diseases in relation to having access to reliable or timely information on existing scientific management techniques. It is a widely held view that limited awareness among governmental and non-governmental actors on the role ICT can play in crop disease management and in the wider agriculture sector is a challenge. There are different perceptions on best-bet information delivery tools ranging from 'mobile-based voice response' to 'participatory radio programs' and 'educational videos'. Providing scientific and evidence-based information is a critical factor for the interviewed experts. They argued that if scientifically proven technologies and practices are shared with farmers through available ICTs, farmers are more likely to adopt it as they will see the benefit. For this reason, information contents are mainly developed by subject matter experts within or outside the organizations. They stressed the need for developing a content that is not in contradiction with the government's extension advisory service. The information content in the ATA IVR (Interactive Voice Response) system, the first of its kind in the country, mainly adapted 'improved technology packages' used by the government extension service whereby government experts from ATA, Ministry, and national research centers participated in repackaging the content to fit to the IVR system. An expert in the organization explained if there is a need to update the content by ATA, it has to be approved by the Ministry of Agriculture and Natural Resources for its conformity with governments' recommended practices.

Discussion: a systems thinking perspective

Diagnosis and risk monitoring

The problems mentioned in relation to the limited capacity of extension workers and farmers on diagnosing and monitoring bacterial wilt and late blight, or the resource constraints are more likely manifestations of a more structural problem that appears to be overlooked by many of the actors. Failure to adequately manage a disease can often be traced back to a failure to correctly diagnose or monitor risk levels of the problem (Palmateer et al., 2016). In the management of bacterial wilt and late blight, a preventative attitude is very important as attempting to rescue a field after disease infestation does not give satisfactory results, especially with bacterial wilt. In this regard, disease management practices of the government and those of farmers are by and large campaign-based and reactive rather than being preventive. Practically, preventive approaches for bacterial wilt can range from a containment strategy and strict quarantine measures to practices that are targeted on the reduction of inoculum sources (Yuliar and Toyota, 2015; Miller et al., 2006). In this regard, existing response-based conception and practice of disease management has intrinsically made timely or accurate bacterial wilt or late blight diagnosis and monitoring 'less relevant' in the eyes of decision makers leading to limited effort or investment to improve the technical skills of farmers and extension workers or to allocate the resources required for the work. A recent government strategy document on 'Pest and Disease management' also proclaimed the government's growing recognition that the provision of crop disease management support service has been done only whenever there is an infestation of outbreak proportions reported by farmers (MoANR, 2016). Similarly, the focus on other more important crop insects and diseases by high-level experts and decision makers could be strategically right, but this would also mean that existing reactive disease management culture would even be more pronounced and less organized for bacterial wilt and late blight problems. The absence of accredited national plant protection laboratories along the ministry structure for diagnosing crop diseases, including potato diseases, and lack of monitoring or forecast systems for late blight and quarantine measures for bacterial wilt (Haverkort et al., 2012; Gorfu et al., 2012; MoANR, 2016) are other manifestations of the structural problems that are considerably affecting proper late blight and bacterial wilt diagnosis and monitoring.

The perception by many of the actors, including the government, that disease diagnosis or risk assessment is an activity of the government has important implications from a systems perspective. Successful disease diagnosis or risk assessment approaches require networks of actors from the government, research institutions and local organizations which help to integrate risk assessment and monitoring activities on diseases (Mazet et al., 2014; Kelly et al., 2017). There seems to be a high tendency, both by the government and other actors, to see disease monitoring and risk assessment as the government's task. The tendency to underemphasize the role of other actors, which we consider as a structural problem, is limiting actors' capacity to collectively act in diagnosis and monitoring of the disease.

Management strategies

Disease diagnosis and monitoring, and implementing management options are related activities. As highlighted before, most disease control measures should aim at preventing or protecting crops from the disease rather than 'curing' the crop after it is diseased (Yuliar and Toyota, 2015; Miller et al., 2006). In systems thinking terms, the underemphasis in bacterial wilt and late blight diagnosis and monitoring, which is argued to come as a result of the reactive disease management culture, will have negative feedback in pushing actors to stick to the existing dominant reactive management approach (Senge, 2006; Kim and Anderson, 1998). Owing to this, the predominant management practices, roguing for bacterial wilt and fungicide application for late blight are done after the incidence of the diseases. Such reactive responses might seem logical at the time of bacterial wilt or late blight prevalence and can indeed suppress the problem at that particular point in time but it has little long-term effect in curbing the recurrence or the fast spread of the diseases. The government has just recently acknowledged that bacterial wilt of potato which used to be a problem in few places has now turned into a national problem due to the existing management responses that are tactical rather than strategic (MoANR, 2016). A recent study by a national research center associated the problem with existing neglect for bacterial wilt suggesting the need for recognizing the potential danger of the disease to the potato growers in the country (Gorfu et al., 2012).

An interesting reactive response mentioned by workshop participants that is also criticized by a previous study is the shift in potato production in many parts of the country from the long rain season (*Meher*) to the short rain (*Belg*) production, despite the high yield potential in the long rain season (Bekele and Eshetu, 2008). Promoting preventive late blight management options without sacrificing yield as a result of shifting to the short rain season could have been a more systemic response. This is with the rationale that the overall objective of late blight disease management is taken to be improving potato productivity or reducing the associated yield loss (Kirk and Wharton, 2014; Burke, 2017). Application of fungicide is the most widely used late blight management practice by potato farmers in the country (Mekonen et al., 2011; Kassa and Beyene, 2001). However, uncontrolled application of fungicide is recognized for its contribution to the development of chemical resistance in the country (MoANR, 2016). The same practice, if supported with a monitoring and information sharing mechanism on when and how to apply chemicals before late blight incidence could have been a preventive option for the disease (Pernezny et al., 2016). Such 'event' level responses could not fundamentally prevent the disease epidemics from recurring season after season or could not significantly reduce initial sources of infections.

Another notable finding from actors' views in relation to the management of the two diseases is the tendency to look at the problem situation from one's own organizational mandate or area of involvement. This is evident from the diverging views of actors on the appropriate management options for the diseases. Successful implementation of preventive management options is affected by existing perceptions towards the need for coordinating efforts. Addressing complex challenges like bacterial wilt and late blight requires that interdependent actors navigate the complexity with the help of continuous monitoring and learning, and translate progressive insight into effective coordinative capacity and collective action (Maloy, 2005). Actors' behavior to collaborate or collectively engage is highly influenced by how the different actors see their roles and scope of influence in the disease management system (Senge, 2006; Kim and Anderson, 1998). However, due to a strong emphasis on one's own organizational mandate or limited recognition of interdependencies of activities, which the different aspects of it will be discussed in the subsequent sections of this paper, successful joint engagement could not be materialized. The existing firefighting mode does not particularly work for the management of bacterial wilt, which usually demands combinations of management options that can best be implemented collectively by farmers in a village or a district (Bekele and Eshetu, 2008).

Seed quality control

Through a systems thinking lens, one can clearly observe a fixation on responding to a short-term situation in relation to the different problem aspects of seed quality control. Apparently, emergency seed potato provision, in a poor disease management culture, will not only advance the spread of the diseases, it can also contribute to other emergency situations when one takes into account the economic importance of the two diseases for potato growers (Gorfu et al., 2012; Kassa, 2012). As can be witnessed from the utterances of the inspectors, whenever potato seed quality control issues were raised, the inspectors mainly talked about event-level interventions like doing a timely inspection, giving instructions, warnings or revocation of license. The 'quick fix' solutions and a focus on their own activities have gravitated the actors to blame others for the problem without acknowledging that their own action is affecting the behavior of other actors thus creating the very problem that they blame others for (Senge, 2006). Similarly, the seed potato producing farmers in the cooperatives or the NGOs could have a chance to proactively work to change their own practices in the production or distribution of disease-free seeds but instead, they are more inclined to superficially react to the regulatory and procedural demands of the inspectors who primarily see strict enforcement as their main course of action. There is no doubt that enforcement of the regulations is necessary. However, a more systemic response could have been facilitating conditions for joint learning to improve the knowledge and technical capacities of potato growers and experts on the diagnosis, monitoring, and management of the two diseases (Maloy, 2005). This does not only help growers to produce disease-free potato seeds that different actors buy and distribute to different areas, it can also lessen the burden on the inspectors who are stretching their limited capacity to casually address bacterial wilt and late blight problems through enforcement of laws and procedures.

Research and extension

As stated by the researchers, over the years, limited adoption of agricultural technologies by farmers through the conventional research and extension approach has indeed brought a shift of emphasis towards participatory research and extension approach in the country (Bedane and Kuma, 2002). It was envisaged that the new approach will bring together the knowledge capacities of local communities with that of scientific institutions and other stakeholders in processes of technology development and use (Bedane and Kuma, 2002; Tesfaye et al., 2002). However, despite the claim to this shift, it is observable that the traditional technology transfer model is still dominant thinking. Researchers' statements seem to implicitly authorize scientists or research institutes as the only or major suppliers of knowledge products. Existing names of the different research departments are also good imprints of a linear thinking mode. Without working towards a shift from this thinking, the 'participatory approach' cannot facilitate interactive learning processes in the direction of joint creation of knowledge and collective action (Röling and Leeuwis, 2001b). Contrary to this, a striking event-level response or a simple-fix from the researchers to the problem of not getting the required support from extension workers or farmers is paying per-diems or hiring guards. Such responses would likely have a negative long-term effect on the very participatory approach by reinforcing existing attitudes of the extension workers and probably farmers[11] in seeing the research experiments as solely researchers' business.

Moreover, the extension research wing in the national research system is preoccupied with 'technology demonstration' and 'popularization' activities. This limits its research engagement on wider systemic issues or in knowledge brokering which could have contributed to institutional innovation and transformation of the enabling environment for technology development and use (Turner et al., 2016; Turnhout et al., 2013). However, as to what seems to be a total disregard for this structural problem, the decision made by SARI is to dissolve the 'Extension Research' department. A shift from a linear knowledge/ technology transfer culture could have been a generative response to improve the effectiveness of the participatory research and extension approach and its contribution to co-creation of knowledge and technologies that are more relevant to the management of bacterial wilt and late blight.

From the utterances of the different actors, one can observe similar defensive routines by the different actors while explaining the different aspects of the problem situation. Such propensity of shifting responsibilities is also reflected in the Ministry's strategy

11 We could not capture farmers' opinion as none of the farmers approached for the study said they had experience in participatory research.

document whereby its linkage with the national crop protection research has remained a very loose owing to the research institute's low focus on plant protection technology generation (MoANR, 2016). From a systems thinking perspective, the tendency to engage in a blame-game or to see themselves in isolation has led them to look for an external cause to the problem situation (Senge, 2006).

Politics and power relations

As people have a particular way of viewing the world, judgments to be made or 'actions to improve' a problem situation should seek accommodation or deliberation among different views and interests of actors. So politics is taken to be a power-related activity concerned with managing relations between different views and interests (Checkland, 2000). Bearing the mantle of leadership in 'smallholder-based sustainable agricultural growth and development' (Chanyalew et al., 2010), the government is playing a very dominant role in planning and agenda setting in a hierarchical and top-down fashion. By the virtue of emphasizing on the expediency of this approach, some of the decision makers and experts in the government showed little regard for any power asymmetry that could arise from the top-down decision-making process. Even though the government's approach might have emanated from pure ambition and an assumed leadership role, a vision that does not appreciate the interests and aspirations of the farmers or other actors can fail to inspire genuine enthusiasm. Decision-making processes can be transformed if all concerned actors become more able to surface and discuss productively their different interests and aspirations (Senge, 2006).

Strong dominance of the government ministry and its downward structure also seems to affect perceived capacity of other actors to instigate change in the system. This is clearly visible in the opinions of researchers and NGO experts on their perceived limited ability to change the problem situation and on the importance of aligning their activities with the agenda set by the government. In system thinking terms, such attitude and associated behavior create a difficult condition for all the actors to fully realize or unleash their potential for coordinated action (Senge, 2006). Although meaningful change can best be realized when powerful actors like the government see the importance of accommodating different interests, the belief of the other actors that change has to come from outside (the government) is characteristic of non-system thinking. It is when actors see themselves as part of the systemic structure that they realize they have the power to alter the structure of the system (Mazet et al., 2014; Kim and Anderson, 1998).

Farmers, who usually are claimed to be 'key partners' by the different actors, find themselves even in a more difficult situation to express their interests. Some of the common utterances from farmers clearly reveal their perceived position in existing power relations. A previous study on participatory natural resource management intervention in the country also supports our assessment that a restrictive political context and widely held negative attitudes towards farmers have undermined self-confidence among farmers, many of whom seem to have internalized the perception that experts and decision makers have towards them (Cullen et al., 2014). The perception that lack of knowledge of farmers is a key problem has shifted the focus of actors towards training and capacity building activities. However, different literature on power relations has already underscored that such interventions can potentially mask or exacerbate the more structural problem of power inequalities if existing power dynamics and the need for accommodation of different interests are not taken into account (Cullen et al., 2014; Aarts and Leeuwis, 2011).

Information sharing culture

As interactions are quite centralized and hierarchical, information sharing is practiced in the same mode. As part of an attempt to come up with a different approach, there have been some experiments on participatory information sharing and learning platforms by different international research-for-development organizations, particularly CGIAR institutes working in the country (Lema et al., 2015; Swaans et al., 2013; Abate et al., 2011). Although so far there is very limited local scientific evidence on the impact of such platforms in fostering interactive information and knowledge sharing or learning, a key insight from one empirical study in the country is of particular importance to our research topic. The study amplified that a failure to take into account power imbalances and political realities in and around learning platforms did not only gave the illusion of increased participation and learning but it also compromised the capacity of the platforms in catalyzing social change (Cullen et al., 2014).

Organizations that are engaged in the delivery of agricultural information through different ICT tools appear to have a shared ‘technology-oriented’ approach to information sharing which assumes that farmers will act in accordance with the implemented technology (Pilerot and Limberg, 2011). The experts mainly talk about how the information delivery tools can facilitate or improve farmers’ or other actors’ access to information, giving little emphasis to the existing top-down culture and power relations which are indicated to influence how actors access, interpret, share or use information (Banjade et al., 2006; Leeuwis, 2004). Due to existing perception of information sharing as a technical rather than a social phenomenon (Checkland, 2000), the development of the information content that is delivered through the different ICT technologies is essentially expert-driven. The ATA approach can be a case in point whereby without changing the logic of content development or information sharing culture, their practice might have even increased the power of the ministry through its control on the information. Using ICTs to enable participatory and interactive information sharing is in stark contrast with classical, expert-centered approaches where ICTs are used primarily to support the dissemination of research-based information and advice (Cieslik et al., 2018; Leeuwis, 2004). On the other hand, if ICT-based interventions are context-specific and build on local needs and capacities, it may enable the generation of new forms of locally relevant information and can catalyze new forms of network formation, information sharing and learning Cieslik et al., 2018; Chapman and Slaymaker, 2002).

Opportunities for ICTs in overcoming collective action problems

Finally, our systemic analysis envisages to look for opportunities for leverage or small, well-focused interventions that have the potential of producing significant and enduring improvements to the problem situation (Senge, 2006). As it is discussed under the technical aspect of the problem situation, actors' limited recognition of interdependency and existing marginal collaboration poses a challenge to effectively monitor and manage the problem of bacterial wilt and late blight. The collective engagement problem becomes even more pronounced when the aim of disease management is geared towards disease prevention rather than disease control (Mazet et al., 2014). This is with the rationale that timely monitoring and risk information sharing, which are vital elements of preventive disease management strategy, require a network of actors that should work towards reducing reoccurring risks of the diseases at the collective level (Liao et al., 2016). In this regard, different ICT platforms have been implicated to play a meaningful role in overcoming connectivity problems or in complementing traditional collective action networks that aim to address complex challenges such as potato disease management (Karpouzoglou et al., 2016; Chapman and Slaymaker, 2002; Cieslik et al., 2018).

However, as highlighted in the introduction, the potential of ICTs to address coordination problems should be seen within the wider social, political and cultural context in which they are supposed to be used (Bennett and Segerberg, 2012; Chapman and Slaymaker, 2002). The amplifying function of digital technologies can, in fact, serve to perpetuate existing inequalities instead of eradicating them (Cieslik et al., 2018). If ICTs have to realize their full potential in contexts with limited horizontal and democratic information flow, active participation of actors at the periphery in the design, experimentation, and use of the digital platforms is crucial (Chapman and Slaymaker, 2002). In our problem context, farmers and lower level (district) actors, which seems to be prime victims of existing power asymmetries and top-down information sharing, could be potential target groups for any ICT-supported collective disease management intervention. In doing so, the platforms will have the possibility to structurally alter the existing top-down flow of information and power inequalities by decentralizing information flow, devolving ownership over information and knowledge, decreasing dependency and providing a framework for shared learning (Karpouzoglou et al., 2016; Chapman and Slaymaker, 2002). Moreover, designing ICT supported collective disease management interventions that target high-level actors at national or regional levels can potentially fail to bring genuine enthusiasm due to the prevailing focus on the management of other insects and diseases of strategic crops. Although bacterial wilt and late blight management are still weak at the district level owing to the overall reactive disease management culture, the disease problem appears to be more recognized or felt by actors operating at the local level.

As noted by Cieslik et al., different forms of participatory digital platforms in combination with more conventional forms of interpersonal communication and mass media can foster new kinds of connectivity, and enable the collection, processing and exchange of information among different actors or members of a community (Cieslik et al., 2018). Mobile phone technology has rapidly been accepted in rural communities and is playing an important role in fostering interaction between farmers, extension bodies and institutions (Chapman and Slaymaker, 2002; Chou and Min, 2009). Given the absence of potato disease forecast or early warning system in the country, ICT supported decision support tools can have a potential contribution in the generation and exchange of information that serves to initiate collective risk monitoring of late blight and in curbing existing practices of fungicide spray that is being done after late blight occurrence. Sharing information on the likely hood of late blight occurrence and on preventive spray regimes that help growers and other local actors for individual or collective decision is now becoming easier through mobile phone networks in places with low internet penetration like Ethiopia (Nakato et al., 2016). Likewise, digital platforms can play a role in the exchange of information on the different disease dynamics of bacterial wilt (e.g. prevalence, diagnosis, monitoring and control options). This can help the actors to better recognize the risks of bacterial wilt which seems to get limited attention so far. Most importantly, information sharing and learning on the risks and management of bacterial wilt can assist potato growers to advance their unsuccessful practice (Roguing) in the management of the disease. With the help of mobile phones, participatory monitoring can be performed by groups of community members which can foster joint learning on the disease dynamics and enhance awareness on the need for cooperation to effectively deal with it (Trabucco et al., 2013). By designing a more bottom-up and participatory approach to content development and technology modification to better fit into local needs, existing infrastructure such as the ATA AVR system can be leveraged to better ensure institutional embeddedness. To this end, further investigation on existing information and knowledge needs in relation to the diagnosis and management of each disease would help to arrive at specific recommendations on best-bet technology options and the content of information that can be used to catalyze disease monitoring, broader learning, and collective action.

Conclusion

This study attempted to assess actors' understanding of the problem situation in the management of bacterial wilt and late blight along multiple and interacting technical and institutional problem dimensions (Figure 1). In so doing, it further explored its implication for management of the two diseases and the role ICT can play in overriding collective action problems. As it is demonstrated in our analysis in Section 5, actors essentially overlooked key systemic problems that are contributing to the continuation or even worsening of the disease problems. Lack of preventive management culture**,** limited recognition of interdependencies among activities of actors, power inequalities, top-down and linear approaches in information and knowledge sharing are among the key structural problems identified. Consequently, management responses are mainly geared towards uncoordinated short-term reactions that were found to have limited effect in catalyzing fundamental change to the systemic problems of bacterial wilt and late blight management. Figure 1 depicts actors' key reactive responses (ERs) and the systemic structure at play (ST) across various technical and institutional aspect of the problem situation represented by the four circles with smaller arrows. It is further summarised in the figure that the systemic problems within the different problem aspects interact with one another to bring about a complex problem situation in the management of bacterial wilt and late blight.

Likewise, the existing appreciation of the problem situation has pushed many of the actors to mainly focus on their own activities and decisions with little recognition that the structural problems are results of multiple interacting factors to which they themselves, knowingly or unknowingly, have contributed their share. This is evident in actors' tendencies to shift responsibilities and engage in a blame-game when discussing the different problem aspects of the diseases. In light of our research questions, we can conclude that existing understanding of actors of the systemic structure has limited their capacity to effectively and jointly respond to the complex problem of late blight and bacterial wilt management.

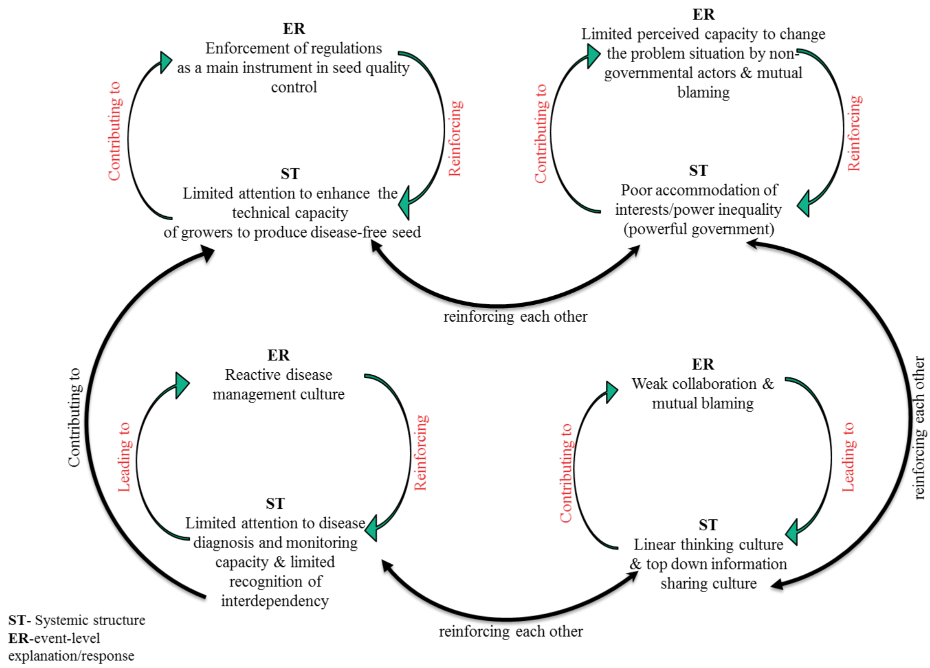


Figure 1:

Systemic structure at play in complex problem of management of bacterial wilt and late blight.

As problems of bacterial wilt and late blight management have multiple technical and institutional aspects, new management interventions should also be designed in such a way that the interventions can instigate technical (preventive disease management) as well as institutional (power asymmetries and top-down information sharing) change. A bottom-up and participatory disease management approach can serve as a 'local' solution to a wider systemic problem whereby farmers, together with local level actors, can drive a positive change in the bacterial wilt and late blight management system. Local level actors such as extension workers, seed quality inspectors, researchers, and NGOs can be strategized to foster institutional embedding and broader learning.

As it is highlighted in the discussion section, a shift to a more preventive management culture warrants networking of local level actors who can collectively engage in disease monitoring and information sharing on different aspects of bacterial wilt and late blight management. Designing such interactive processes will not only help local level actors to better realize their interdependency and to have a shared understanding of the systemic structure at play, more importantly, it can facilitate collaboration and collective action to deal with their shared problem. In this respect, different forms of digital technologies or information sharing platforms can play a role in facilitating actor networking, information exchange, learning and collective action in the management of the two diseases. A promising intervention for late blight could be a mobile-based decision support tool that can be used for information sharing on disease monitoring and preventive fungicide use. Similar mobile-based digital platforms can be leveraged to enhance awareness and facilitate learning on bacterial wilt disease dynamics and management. To be able to come up with a more specific recommendation, more insight on existing ICT infrastructure, and information and knowledge needs in relation to the diagnosis and management of each disease is of paramount importance.

References

Aarts, M.N., Leeuwis, C., 2010 1. Participation and power: reflections on the role of government in land use planning and rural development. J. Agric. Educ. Extension 16 (June (2)), 131–145.

Aarts, M.N., van Woerkum, C.M., 2005. Dealing with divergence and diversity in policymaking processes. InCoalitions and Collisions. Wolf Publishers (pp. 315–323).

Abate, T., Shiferaw, B., Gebeyehu, S., Amsalu, B., Negash, K., Assefa, K., Eshete, M., Aliye, S., Hagmann, J., 2011. A systems and partnership approach to agricultural research for development: lessons from Ethiopia. Outlook Agric. 40 (September (3)), 213–220.

Abdurahman, A., Griffin, D., Elphinstone, J., Struik, P.C., Schulz, S., Schulte-Geldermann, E., Sharma, K., 2017. Molecular characterization of Ralstonia solanacearum strains from Ethiopia and tracing potential source of bacterial wilt disease outbreak in seed potatoes. Plant Pathol. 66 (June (5)), 826–834.

Apple, J.L., 1977. The Theory of Disease Management. Academic Press, New York. Banjade, M.R., Schanz, H., Leeuwis, C., 2006. Discourses of information in community forest user groups in Nepal. Int. For. Rev. 8 (June (2)), 229–240.

Baye, B., Gebremedhin, W., 2012. Potato research and development in Ethiopia achievements and trends. In seed potato tuber production and dissemination: experiences, challenges and prospects. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination Mar (pp. 12–14).

Bedane, K., Kuma, B., 2002. Farmer participatory research. an overview. Towards Farmers Participatory Research. Central High lands of Ethiopia, pp. 2–8. Bekele, K., Eshetu, B., 2008. Potato disease management Root and tuber crops. Untapped Resour. 79–96.

Bekele, B., Abate, E., Asefa, A., 2012. Viruses and bacterial wilt disease of potato in western Amhara. In seed potato tuber production and dissemination: experiences, challenges and prospects. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination Mar (pp. 241–255).

Bennett, W.L., Segerberg, A., 2012. The logic of connective action: digital media and the personalization of contentious politics, Information. Commun. Soc. 15 (June (5)), 739–768.

Burdon, J.J., Barrett, L.G., Rebetzke, G., Thrall, P.H., 2014. Guiding deployment of resistance in cereals using evolutionary principles. Evol. Appl. 7 (June (6)), 609–624.

Burke, J.J., 2017. Growing the Potato Crop. Vita, Equity House, Upper Ormond Quay, Dublin, Ireland.

CSA (Central Statistical Agency), 2006. Agricultural Sample Survey, Report on Area and Production of Crops. Statistical Bulletin, Addis Ababa. Ethiopia.

CSA (Central Statistical Agency), 2016. Agricultural Sample Survey, Report on Area, Production and Farm Management Practice of Belg Season Crops. Statistical Bulletin, Addis Ababa. Ethiopia.

Cabrera, D., Colosi, D.L., Lobdell, C., 2008. Systems thinking. Eval. Program Plann. 31 (August (3)), 299–310.

Chanyalew, D., Adenew, B., Mellor, J., 2010. Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) –2020. Federal Democratic Republic of Ethiopia Ministry of Agriculture and Rural Development.

Chapman, R., Slaymaker, T., 2002. ICTs and Rural Development: Review of the Literature, Current Interventions and Opportunities for Action. ODI (Overseas Development Institute).

Checkland, P., 2000. Soft systems methodology: a thirty year retrospective. Syst. Res. Behav. Sci. 1 (November (17)), (S1).

Chou, S.W., Min, H.T., 2009. The impact of media on collaborative learning in virtual settings: the perspective of social construction. Comput. Educ. 52 (February (2)), 417–431.

Cieslik, K. J., Leeuwis, C., Dewulf, A. R. P. J., Lie, R., Werners, S. E., Van Wessel, M., P. Feindt, and Struik, P. C. 2018. Addressing socio-ecological development challenges in the digital age: Exploring the potential of Environmental Virtual Observatories for Connective Action (EVOCA). *NJAS-Wageningen Journal of Life Sciences*, *86*, 2-11.

Cullen, B., Tucker, J., Snyder, K., Lema, Z., Duncan, A., 2014. An analysis of power dynamics within innovation platforms for natural resource management. Innov. Dev. 4 (July (2)), 259–275.

ESA (Ethiopian Standard Authority), 2015. Quality Declared Seed (QDS), Vegetatively Propagated Potato Seed – Specification, first ed. Addis Ababa, Ethiopia.

Franc, G.D., 1998. An Introduction to Plant Pathology and Plant Disease Management. University of Wyoming, Cooperative Extension Service.

Garuma, L., Dechasa, N., Mekibeb, F., 2012. Seed system analysis of potato in Guraghe highlands. In Seed potato tuber production and dissemination: experiences, challenges and prospects. In: Woldegiorgis, G., Schulz, S., Berihun, B. (Eds.), Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination, Mar (pp. 307–323).

Gildemacher, P.R., Kaguongo, W., Ortiz, O., Tesfaye, A., Woldegiorgis, W., Wagoire, W.W., Kakuhenzire, R., Kinyae, P.M., Nyongesa, M., Struik, P.C., Leeuwis, C., 2009. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Res. 52 (May (2)), 173–205.

Gorfu, D., Woldegiorgis, G., Kassa, B., 2012. Bacterial wilt an emerging threat to Ethiopian potato industry. In seed potato tuber production and dissemination: experiences, challenges and prospects. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination Mar (pp. 211–222).

Guest, G., Bunce, A., Johnson, L., 2006. How many interviews are enough? An experiment with data saturation and variability. Field Methods 18 (Februay (1)), 59–82.

Haverkort, M., Koesveld, H., van Schepers, J., Wijnands, R., Wustman Zhang, X., 2012. Potato prospects for Ethiopia: on the road to value addition. Lelystad: PPO-AGV 66.

Hirpa, A., Meuwissen, M.P., Tesfaye, A., Lommen, W.J., Lansink, O.A., Tsegaye, A., Struik, P.C., 2010. Analysis of seed potato systems in Ethiopia. Am. J. Potato Res. 87 (December (1)), 537–552.

Jørgensen, M.S., Jørgensen, U., Clausen, C., 2009. The social shaping approach to technology foresight. Futures 41 (March (2)), 80–86.

Karpouzoglou, T., Zulkafli, Z., S.Grainger, S., Dewulf, A., Buytaert, W., Hannah, D.M., 2016. Environmental virtual observatories (EVOs), prospects for knowledge cocreation and resilience in the information age. Curr. Opin. Environ. Sustain. 29 (Feb (18)), 40–48.

Kassa, B., Beyene, H., 2001. Efficacy and economics of fungicide spray in the control of late blight of potato in Ethiopia. Afr. Potato Sci. J. 9 (March (1)), 245–250.

Kassa, B., 2012. Control of bacterial wilt and blackleg of potato using effective microorganisms.

In seed potato tuber production and dissemination: experiences, challenges and prospects. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination Mar (pp. 223–232).

Kassa, B., 2016. Potato bacterial wilt management in the Central Highlands of Ethiopia. Ethiopian J. Agric. Sci. 26 (2), 83–97.

Kelly, T.R., Karesh, W.B., Johnson, C.K., Gilardi, K.V., Anthony, S.J., Goldstein, T., Olson, S.H., Machalaba, C., Mazet, J.A., Consortium, Predict, 2017. One Health proof of concept: bringing a transdisciplinary approach to surveillance for zoonotic viruses at the human-wild animal interface. Prev. Vet. Med. 1 (February (137)), 112–118.

Kim, D.H., Anderson, V., 1998. Systems Archetype Basics. Waltham, Mass, Pegasus Communications Inc.

Kirk, W.W., Wharton, P.S., 2014. 11 fungal and bacterial disease aspects in potato production. Potato: Botany, Prod. Uses 167.

Krueger, R., Gibbs, D., 2010. Competitive global city regions and 'sustainable development': an interpretive institutionalist account in the South East of England. Environ. Plan. A 42 (April (4)), 821–837.

Kuarabachew, H., Assefa, A., Hiskias, Y., 2007. Evaluation of Ethiopian isolates of Pseudomonas fluorescens as biocontrol agent against potato bacterial wilt caused by Ralstonia (Pseudomonas) solanacearum. Acta Agric. Solvenica 90 (December (2)), 125–135.

Leeuwis, C., Aarts, M.N., 2011. Rethinking communication in innovation processes: creating space for change in complex systems. J. Agric. Educ. Extension 17 (February (1)), 21–36.

Leeuwis, C., 2004. Communication for Rural Innovation. Rethinking Agricultural Extension, 3rd ed. Blackwell Science, Oxford.

Lema, Z., Damtew, E., Mekonnen, K., Adie, A., 2015. Engaging with Farmers: Experiences from Africa RISING in the Ethiopian Highlands. International Livestock Research Institute.

Lemaga, B., Kakuhenzire, R., Kassa, B., Ewell, P.T., Priou, S., Allen, C., Prior, P., Hayward, A., 2005. Integrated Control of Potato Bacterial Wilt in Eastern Africa: the Experience of African Highlands Initiative. Bacterial Wilt Disease and the Ralstonia Solanacearum Species Complex. pp. 145–157.

Lemessa, F., Zeller, W., 2007. Screening rhizobacteria for biological control of Ralstonia solanacearum in Ethiopia. Biol. Control 42 (September (3)), 336–344.

Liao, W., Yuan, Y.C., McComas, K.A., 2016. Communal risk information sharing: motivations behind voluntary information sharing for reducing interdependent risks in a community. Commun. Res. 1–25. http://dx.doi.org/10.1177/0093650215626981.

Maloy, O., 2005. Plant Disease Management. The Plant Health Instructor 10.1094. PHI-I- 2005-0202-01.

Mazet, J.A., Uhart, M.M., Keyyu, J.D., 2014. Stakeholders in one health. Rev. Sci. Tech. 33 (August (2)), 443–452 International Office of Epizootics.

Mekonen, S., Alemu, T., Kassa, B., Forbes, G., 2011. Evaluation of contact fungicide spray regimes for control of late blight (Phytophthora infestans) in southern Ethiopia using potato cultivars with different levels of host resistance. Trop. Plant Pathol. 36 (February (1), 21–27.

Midgley, G., 2003. Science as systemic intervention: some implications of systems thinking and complexity for the philosophy of science. Syst. Pract. Action Res. 16 (April (2)), 77–97.

Miller, J.S., Nolte, P., Olsen, N., Miller, T., Bohl, B., Thornton, M., 2006. Late Blight Management Action Plan for Potatoes. University of Idaho Extension.

Mingers, J.C., 1980. Towards an appropriate social theory for applied systems thinking: critical theory and soft systeivis methodology. J. Appl. Syst. Anal. 7 (1), 41–50.

MoANR (Ministry of Agriculture and Natural Resources), 2013. ATA (Agricultural Transformation Agency), Ethiopia Seed System Development Strategy.

MoANR (Ministry of Agriculture, Natural Resources), 2016. Pest Management Support Services Strategy for Ethiopia. Government Strategy Document.

Nakato, G.V., Beed, B., Bouwmeester, H., Ramathani, I., Mpiira, S., Kubiriba, J., Nanavati, S., 2016 Jul 2. Building agricultural networks of farmers and scientists via mobile phones: case study of banana disease surveillance in Uganda. Can. J. Plant. Pathol. 38 (3), 307–316.

Palmateer, A., Pernezny, K., Elliott, M., Havranek, N., 2016. Guidelines for Identification and Management of Plant Disease Problems: Part III. Diagnosing Plant Diseases Caused by Fungi, Bacteria and Viruses. Plant Pathology Department, UF/IFAS Extension publication.

Pernezny, K., Elliott, M., Palmateer, A., Havranek, N., 2016. Guidelines for Identification and Management of Plant Disease Problems: Part II. Diagnosing Plant Diseases Caused by Fungi, Bacteria and Viruses. Plant Pathology Department, UF/IFAS Extension publication.

Pilerot, O., Limberg, L., 2011. Information sharing as a means to reach collective understanding: a study of design scholars' information practices. J. Doc. 67 (March (8)), 312–333.

Röling, N., Leeuwis, C., 2001a. Resonances and Dissonances in Development: Actors, Networks, and Cultural Repertoires. Royal Van Gorcum, Assen, The Netherlands, pp. 47–64.

Röling, N., Leeuwis, C., 2001b. Strange bedfellows: how knowledge systems became Longer and why they will never be Long. In: Heninch, P., Verschoor, G. (Eds.), Resonances andDissonances in Development: Actors, Networks, and Cultural Repertoires. Royal Van Gorcum, Assen, The Netherlands 764.

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L.C., Raboanarielina, C.M., Adegbola, P.Y., van Ast, A., Bastiaans, L., 2015. RAAIS Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. Agric. Syst. 31 (January (132)) 1–1.

Seed Proclamation No. 782/2013, 2013. Federal Negarit Gazette of the Federal Democratic Republic of Ethiopia. pp. 19–27.

Senge, P.M., 2006. The Fifth Discipline: The Art and Practice of the Learning Organization (Revised and Updated Edition). Doubleday, New York.

Smith, K., 1997. Economic infrastructures and innovation systems. In: Edquist, C. (Ed.), Systems of Innovation: Technologies, Institutions and Organisations, pp. 86–106.

Stewart, R.B., 1956. Some Plant Diseases Occuring in Kaffa Province. College of Agriculture, Alemaya Ethiopia, Ethiopia, pp. 58–60.

Swaans, K., Cullen, B., Van Rooyen, A.F., Adekunle, A., Ngwenya, H., Lema, Z., Nederlof, S., 2013. Dealing with critical challenges in African innovation platforms: lessons for facilitation. Knowl. Manage. Dev. J. 9 (03), 116–135.

Tadesse, Y., Almekinders, C.J., Schulte, R.P., Struik, P.C., 2017a. Understanding farmers' potato production practices and use of improved varieties in Chencha, Ethiopia. J. Crop Improv. 31 (September (5)), 673–688.

Tadesse, Y., Almekinders, C.J., Schulte, R.P., Struik, P.C., 2017b. Tracing the seed, seed diffusion of improved potato varieties through farmers' networks in Chencha, Ethiopia. Exp. Agric. 53 (4), 481–496.

Tesfaye, A., Yirga, C., Bekele, T., 2002. Experiences of participatory research in the national agricultural research system in Ethiopia. Towards Farmers Participatory Research. Central Highlands of Ethiopia, pp. 12–26.

Thiele, G., Labarta, R., Schulte-Geldermann, E., Harrison, G., 2011. Roadmap for Investment in the Seed Potato Value Chain in Eastern Africa. International Potato Center (CIP), Lima.

Trabucco, B., Chabrier, F., Jori, F., Maestrini, O., Cornélis, D., Etter, E., Molia, S., Relun, A., Casabianca, F., 2013. Stakeholder's practices and representations of contacts between domestic and wild pigs: a new approach for disease risk assessment? Acta Agric. Slovenica Supl. 119–122.

Tsedaley, B., 2014. Late blight of potato (Phytophthora infestans) biology, economic importance and its management approaches. J. Biol. Agric. Health. 25, 215–226.

Turner, J.A., Klerkx, L., Rijswijk, K., Williams, T., Barnard, T., 2016. Systemic problems affecting co-innovation in the New Zealand Agricultural Innovation System: identification of blocking mechanisms and underlying institutional logics. NJASWageningen J. Life Sci. 31 (March (76)), 99–112.

Turnhout, E., Stuiver, M., Klostermann, J., Harms, B., Leeuwis, C., 2013. New roles of science in society: different repertoires of knowledge brokering. Sci. Public Policy 40 (February (3)), 354–365.

UNDP, 2011. An Effective Legal Framework: Seeds and Plant Variety for the Federal Democratic Republic of Ethiopia.

Van der Plank, J.E., 2013. Plant Diseases: Epidemics and Control. Academic Press. Vickers, G., 2013. Value Systems and Social Process. Routledge Tavistock publishers limited.

Yuliar, Y.A., Toyota, K., 2015. Recent trends in control methods for bacterial wilt diseases caused by Ralstonia solanacearum. Microb. Environ. 30, 1–11.

2

3

Chapter 3

Farmers' knowledge and practices of potato disease management in Ethiopia[13]

[13] Published as Tafesse, S., Damtew, E., van Mierlo, B., Lie, R., Lemaga, B., Sharma, K., Leeuwis, C. and Struik, P.C. Farmers' knowledge and practices of potato disease management in Ethiopia. NJAS-Wageningen Journal of Life Sciences, 86, pp.25-38

Abstract

Effective management of potato diseases such as bacterial wilt and late blight depends to a large extent on farmers' knowledge of the diseases as well as on the integration of recommended management methods in their daily practices. Late blight has continued to be a dominant potato disease for many decades in Ethiopia, whereas bacterial wilt has emerged more recently with a devastating impact on the country's potato production systems. A survey of 261 randomly selected farmers was carried out in three major potato growing districts in the central highlands of Ethiopia to examine farmers' knowledge and management practices of the two diseases, and to analyze the role of relevant knowledge in their practices. Considering their different characteristics, three groups of farmers were distinguished: producers of quality declared seed, producers of regular seed and producers of ware. The study sheds light on the vital role the lack of knowledge about the diseases plays in shaping farmers' daily potato production practices. Most farmers could recognize symptoms of the diseases on infected leaves and stems. However, they had very limited knowledge of the diseases including their causal agents, spreading mechanisms, and effective management methods, although they knew a little bit more about late blight than about bacterial wilt. Therefore, to effectively manage the diseases, farmers need to learn about the diseases and how to manage them in their local context applying a feasible combination of management options through a community-based approach. The effectivity of such approach could be enhanced by stipulating operational standards in bylaws and through continuous monitoring of changes in farmers' practices and environmental monitoring for disease occurrence by leveraging interactive mobile-based platform.

Keywords:

Farmers' knowledge, potato diseases, disease management, farmers' practices, bacterial wilt, late blight, Ralstonia solanacearum, Phytophthora infestans

Introduction

Potato (Solanum tuberosum L.) is the fourth most important food crop in the world after maize, rice, and wheat. It provides more food per unit area than any other major food crop (Devaux, et al., 2014; FAO, 2008). In Ethiopia, on top of being a key crop for food and nutrition security, potato is a vital source of income for many smallholder farmers in the Ethiopian highlands due to its high yield, combined with its early maturity and high nutritional value (Haverkort et al., 2012; Gildemacher et al., 2009a). Currently, potato is cultivated on more than 296,000 ha of land in the country, engaging more than 3.7 million smallholder farmers and with an annual production of about 3.6 million tonnes (CSA, 2016).

Despite its importance, the production of potato has been challenged by several biotic and abiotic constraints prevailing in the country. Potato yield per unit area has remained low with a national average of approximately 12.3 Mg/ha (CSA, 2016), which is low compared to the achieved yield of up to 65 Mg/ha on research station and about 50 Mg/ha on farmers' field, under good management practices and using improved varieties (Berihun and Woldegiorgis, 2013).

Among the major biotic constraints that have severely affected potato production in Ethiopia, late blight has been identified as the most important (Kassa and Eshetu, 2008; Woldegiorgis et al., 2008). The pathogen develops and spreads rapidly under high relative humidity, moderate temperature, and substantial rainfall. It infects potato leaves, stems, and tubers at any stage of development and has a potential to destroy the whole potato field within a few days.

Considering the importance of the late blight problem, several potato research and development projects have been implemented in the country. Late blight management approaches which include the use of resistant varieties, fungicide application, and cultural practices such as early planting, hilling and mechanical haulm killing before harvesting have been tested and recommended by the national agricultural research institute (Woldegiorgis et al., 2008). Studies show that management practices such as fungicide application and use of resistant varieties have been adopted by some potato farmers in different parts of the country (Tesfaye, et al., 2013). However, late blight has continued to be a serious problem contributing to a significant yield reduction in the Ethiopian potato production system.

More recently, another potato disease, bacterial wilt, has become the most serious threat to the country's potato production (Gorfu and Woldegiorgis, 2013). The prevalence of bacterial wilt has been historically limited to few parts of potato-growing areas in Ethiopia until recent years (Henok, et al., 2007; Lemessa and Zeller, 2007). With the rapid expansion of potato production in the country, the distribution of the disease has been increasing. And currently, the disease has spread nationwide. According to recent studies, the disease has affected the seed potato production system and it has reached an epidemic level in some districts (Abdurahman et al., 2017; CIP, 2016; Gorfu et al., 2013). Overall, given the drastic prevalence of both bacterial wilt and late blight in the country, controlling the spread of the diseases is currently a big concern of potato farmers and other actors in the potato innovation system.

In the literature, much is known about the nature of the pathogens that cause the two diseases and effective measures for prevention and control of their spreading (Yuliar et al., 2015; Arora et al., 2014; Hayward, 1991). This does however not imply that smallholder potato farmers in developing countries like Ethiopia have adequate knowledge of the diseases given the complex socio-ecological nature of these problems. A recent diagnostic study conducted in the Ethiopian potato innovation system and published in this special issue has pointed out that the design and implementation of effective management interventions for the two diseases requires an understanding of the systemic, multiple and interacting technical and institutional aspects (Damtew et al., 2018). The study recommends a community-based approach (mobilizing farming community and strategizing other local actors) to effectively manage the diseases in the context of smallholder farmers in Ethiopia (Damtew et al., 2018). Similarly, previous studies in many countries have recommended an integrated approach using a combination of disease management options as a plausible strategy to effectively manage bacterial wilt (Lemaga et al., 2005; Priou et al., 1999; French, 1994; Elphinstone and Aley, 1993) and late blight (Cooke et al., 2011; Garrett et al., 2001; Lal et al., 2017). Furthermore, addressing such complex socio-ecological challenges requires continuous monitoring and learning, and translating new scientific knowledge to foster the capacity of farmers to act collectively (Cieslik et al., 2018; Brown et al., 2010).

In the current digital era, the increasing availability of Information Communication Technologies (ICTs) has enabled management and monitoring of complex ecological challenges by generating timely and context-specific information (Cieslik et al., 2018). Likewise, in relation to complex potato diseases like bacterial wilt and late blight, mobile-based technologies have been suggested as potential ICTs to stimulate collective and connective action among farmers by generating locally relevant information (Cieslik et al., 2018; Damtew et al., 2018). However, the extent to which farmers in Ethiopia have access to mobile phones and how mobile-based platforms can be leveraged for disease monitoring and information sharing among smallholder farmers are not clear. Furthermore, for developing an effective community-based approach, good insight into farmers' knowledge and information need in relation to the different aspects of the diseases is required. Understanding the role of knowledge in farmers' practices is also an important starting point for developing a community-based management strategy that fits the context of the country's potato production systems.

This diagnostic study was designed to investigate farmers' knowledge of various aspects of bacterial wilt and late blight and to examine how the knowledge on these diseases contributes to or hinders good farmers' practices of preventing and controlling the diseases. It is recognized that relevant knowledge may consist of both scientific knowledge and local knowledge and abilities to deal with the diseases in the local context. Hence, the study focuses on farmers' understanding of scientific knowledge on the diseases and recommended management methods as well as their local knowledge on how to deal with the diseases. The findings of this study are relevant for the design of a community-based potato disease management in the context of smallholder farmers in Ethiopia. Moreover, the study offers an important scientific contribution to our theoretical understanding of how farmers' practices are related to knowledge in relation to the management of plant diseases and how mobile-based technologies can foster disease monitoring and collective action. The main objective of the study is to identify basic requirements for a community-based management strategy that induces a learning process among farmers for effective management of bacterial wilt and late blight in the central highlands of Ethiopia. The implications of the study will be identified by exploring what types of learning approaches would fit the current situation of farmers' knowledge and practices. To achieve the overall objective, four related research questions were formulated:

1. What would be an effective disease management strategy for smallholder potato farmers?

2. What knowledge do farmers have about bacterial wilt and late blight and their management methods?

3. How are farmers' practices related to this knowledge?

4. What are the implications for a community-based intervention and monitoring approach by leveraging a mobile-based platform?

This paper is organized as follows. Section 3.2 develops a conceptual framework for the study. This is followed by Section 3.3 with a brief description of the methodology including study design and sample selection, description of study sites, data collection and analysis, and profile of sample farmers. In Section 3.4, the results are presented, and in Section 3.5 the findings are discussed. Section 6 draws conclusions.

Conceptual framework

The purpose of this section is to present a conceptual framework employed in this study. Three concepts relevant to crop disease management are key in this study. These are potato diseases, knowledge and practices.

Potato diseases

Plant diseases result from complex interactions among a susceptible host plant, a pathogen, and the environment (Vanderplank, 2012; Scholthof, 2007). Several human activities like cultural practices including application of chemicals modify this interaction (Burdon et al., 2014). Environmental factors such as temperature, moisture, soil pH, wind, light, and soil type play a huge role in disease development and severity (Scholthof, 2007; Schumann, 1991). Plants are considered to be diseased when they are infected by a pathogen and their normal development and functioning are disrupted. Hence, plant diseases significantly diminish growth and yield or reduce the usefulness of a plant or a plant product (Van der Plank, 2013; Beresford, 2007). Plant diseases may also lead to complete destruction of the entire plant under conditions favorable for the disease. Plant diseases can be grouped by the causal agent involved such as fungal diseases, bacterial diseases, and viral diseases (Vanderplank, 2012; Schumann and D'Arcy, 2006). Good understanding of the pathogen that causes a disease, its characteristics and life cycle, and its effective management options are critical to control or suppress the adverse effects of a plant disease (Van der Plank, 2013). This study focuses on the two major potato diseases in Ethiopian potato production systems, bacterial wilt and late blight, which are complex ecological problems. These diseases are caused by pathogens that have intricate life cycles and diverse spreading mechanisms.

Knowledge

For effective management, farmers need to have good knowledge of different aspects of the diseases, such as causal agents of the diseases, their life cycle, their visible symptoms on infected potato plants and tubers, how they spread from one area to another or from one plant to another, and effective management options. Without knowledge of these features of the diseases, it is difficult to effectively deal with them.

Knowledge is a generic concept that needs to be specified to be a useful analytical tool. Scholars from many fields have developed different perspectives and attach different meanings to the concept of knowledge. For Churchman (1971), knowledge is a collection of information, as an activity or as a potential residing in the user to help him adjust behavior to changing conditions. Taking an interpretive view, Davenport and Prusak (1998) define knowledge as "a fluid mix of framed experience, values and contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information." According to this perspective, knowledge originates from and is applied by humans.

Different taxonomies of knowledge have been proposed by different scholars that got prominence in different scientific or practice domains. Lundvall and Johnson (1994) consider knowledge as a key resource for economic growth. They categorize relevant knowledge into four broad categories: know-why (scientific knowledge of principles or interpretative frameworks based on experience and intuition), know-what (knowledge about facts), know-how (skills of doing different kinds of things practically) and know-who (who knows what and can do what). Know-what and know-why are usually referred to as explicit knowledge since they are easy to codify and communicate whereas know-how and know-who are tacit knowledge, which is invisible and difficult to share (Nonaka, 1991; Polanyi, 1967). This perspective on knowledge has gained prominence among innovation scholars who study learning economies. Learning mechanisms are also related to the type of knowledge to be generated, exchanged or transferred. Know-what and know-why are primarily learned by reading books and other materials and attending lectures or trainings while learning know-how and know-who is primarily rooted in experiential learning and in social interaction (Lundvall, 1992).

As disease management entails implementing a range of activities that require different types of knowledge, our study borrowed this perspective to examine the different knowledge aspects of farmers in the management of bacterial wilt and late blight. In the context of this study, know-why refers to knowledge on the causal agents and spreading mechanisms of the two diseases as farmers are not necessarily expected to understand the delicate and complex life cycles of the pathogens in order to properly manage the diseases. Know-what includes farmers' recognition of the diseases, symptoms on infected potato plants and tubers, diagnosis methods, and management methods, whereas know-who refers to farmers' knowledge of who can provide relevant information or their sources of information in their respective areas in relation to effective management of the two diseases, including fellow farmers, extension workers, NGO staffs and researchers, among others. Finally, know-how refers to farmers' skills to implement effective disease management practices.

Practices

Relevant knowledge shapes disease management only if it is integrated into farmers' daily practices. The concept of social practices has been used by many scholars (Shove et al., 2012; Leeuwis, 2004). Practices are patterns of human action that are common in different contexts due to social influences. Peoples' practices are shaped by a number of factors including what they believe to be true (beliefs about consequences of actions/ practices, perceptions of likelihood and risk), what they aspire to achieve, what they think they are able to do (which includes availability of skills and competence), and what they think they are allowed and/or expected to do (Leeuwis, 2004). Likewise, according to Shove et al. (2012), a social practice is defined by available materials (things, technologies, and physical entities), competences (skills, know-how, and techniques) and the meaning attributed to it (symbolic meanings, ideas and aspirations). This perspective contends that while people may know why, in order to integrate relevant knowledge into their practices, it must be meaningful in their local context, they need to possess or have access to appropriate technologies and develop appropriate skills and local knowledge of how to apply scientific knowledge in a specific context. This concept of practices thus allowed us to give special emphasis to the role of knowledge in farmers' practices of bacterial wilt and late blight management.

Materials and methods

Study design and sample selection

A survey aimed at understanding farmers' disease management practices and their knowledge of bacterial wilt and late blight was conducted. To select sample farmers, a multistage sampling technique was used.

In the first stage of selection, three sample districts (Gumer, Doyogena and Wolmera) were chosen purposefully from two major potato growing regions of the country, Southern Nations, Nationalities, and Peoples' (SNNP) region, and Oromia region. These districts are among the major potato growing districts located in the central highlands of Ethiopia. Due to variations in terms of local conditions such as agricultural production systems and access to potato technologies, the districts were selected purposefully for the study expecting variations in farmers' practices in relation to potato disease management. Gumer is located in the Gurage zone of SNNP region at 220 km from Addis Ababa. The agroecology of the Gumer district is moist cool highlands with bimodal rainfall and with annual rainfall of about 1600 mm. Its altitude ranges from 2800-3000 m. Doyogena district is also located in the SNNP region of Kampata Tembaro zone, at about 260 km south west of Addis Ababa, with an altitude ranging from 1900 up to 2800 m. The district also has a bimodal distribution of rainfall with an annual rainfall of around 1400 mm. Wolmera district is located in the Oromia region, about 40 km west of Addis Ababa, with a bimodal rainfall distribution. This district receives an average annual rainfall of around 1100 mm and its altitude ranges between 2060 to 3380 m. Wolmera district has been one of the hubs of the seed potato market over the last 15 years since the Holeta Agricultural Research Center (HARC) of the Ethiopian Institute Agricultural Research (EIAR) and the International Potato Center (CIP) have been operating in the area. HARC and CIP have started operating in Gumer and Doyogena districts in recent years. This may probably lead to different disease management practices among the districts since the farmers in Wolmera district have had relatively better access to information on potato production and disease management practices.

In the second selection stage, three broad categories of potato farmers were discerned, because their knowledge was expected to differ (although the categories were not mutually exclusive): producers of quality declared seed (QDS), producers of regular seed and producers of ware potatoes. QDS producers are farmers who are registered to produce seed that conforms to the minimum standards for seed potato production and undergoes some certification process (CIP, 2016; ESA, 2015) that is legislated in the seed production law. Since they are required to understand and adhere to quality seed production procedures stipulated in the QDS regulation they must have good knowledge of potato diseases and potato production practices and inform themselves. Regular seed producers are those farmers who are usually organized in groups or cooperatives to produce seed potatoes. Their seed does not pass a certification process, but is expected to meet minimum requirements and therefore these farmers should have better knowledge than ware producers. Ware producers produce table potatoes either for home consumption or for marketing. There are no quality standards for ware potatoes. The knowledge of ware growers about diseases is expected to be least because they primarily get information from fellow farmers and extension workers unlike producers of QDS and producers of regular seed who get substantial support from agricultural research centers, universities and non-governmental organizations.

Lists of potato growers (population) in the study sites were obtained from the respective district offices of agriculture and natural resources and sample farmers were randomly selected from these lists. The sample size was determined with the proportional stratified sampling method, with 95% confidence interval and 5% margin of error. Overall, a total of 261 farmers were selected and interviewed in the field. Detailed numbers of interviewed sample farmers are indicated in Table 3.1.

Table 3.1: Numbers of interviewed farmers.

	Number of sample farmers			
Sample districts	**QDS producers**	**Regular seed producers**	**Ware potato producers**	**Total**
Gumer	23	27	32	82
Doyogena	17	18	41	76
Wolmera	-	40	63	103
Total	40	85	136	261

Data collection and analysis

A questionnaire developed by the researchers was used to collect data from the sample farmers. The questionnaire was aimed at getting a clear picture of farmers' knowledge of bacterial wilt and late blight. Both structured and semi-structured questions were used.

Farmers' know-why and know-what were investigated by comparing the current knowledge of scientists with farmers' knowledge of the generic issues of the nature of the disease, causes of the spreading of the disease and disease management. The review of the state-of-the-art of scientific knowledge of bacterial wilt and late blight was carried out on the basis of a literature study (the know-why among scientists; see Sections 3.4.1 and 3.4.2).

The tacit knowledge forms of know-who and know-how are ideally investigated with participant observation and long, in-depth interviews. The know-who was investigated by asking about the farmers' knowledge not only about the sources of information, but also about the type of knowledge obtained from different sources and whether mobile phones were sufficiently used by farmers to be future source of information were explored. To tackle the potential drawbacks of asking about know-how in a survey, the farmers' were questioned about their actual disease management practices. Hence, practices such as crop rotation, seed renewal, use of late blight resistant potato varieties, and sorting infected/damaged seed and ware potatoes at harvest were given due attention in the questionnaire about how to address the diseases. Moreover, to triangulate and complement the findings of the survey, additionally in-depth interviews were conducted with six purposely selected farmers to generate qualitative information about their know-how and know-who.

The questionnaire was pre-tested with three farmers in each sample district. Few revisions on the content and the ordering of questions were made based on observations and reflections from the pre-test. The survey was conducted in a face-to-face interview style during November and December 2016. In addition to the questionnaire, farmers were asked to differentiate the symptoms of bacterial wilt and late blight that they knew during the interview. The questions were supported by providing colored photographs, which showed infected symptoms of bacterial wilt and late blight on potato leaves, stems and tubers.

The survey data were analyzed using descriptive statistics (percentage, frequency and mean) to present findings in summaries and tables. Pearson Chi-square test was used to determine whether there was a significant difference in potato production practices and farmers' knowledge of bacterial wilt and late blight management among farmers of different categories, and study districts. All the quantitative analyses were done using SPSS (Version 22) software.

Profile of sample farmers

Of the 261 respondent farmers for the study, 87% were male and 13% were female. The average age was 42.7 ± 13.1 years, with many farmers (46%) between 36 and 55 years old. The majority of the respondents (67%) had formal education, either primary school (grade 1-8) or secondary school (grade 9-12). Only 18% of the farmers were illiterate. All sample farmers were smallholders, with an average potato farm size of 0.56 ± 0.57 ha; the majority of them (53%) had less than 0.5 ha. Farmers in Wolmera district owned relatively larger potato fields than the farmers in Gumer and Doyogena districts. The average potato field size ranged from 0.37 ha in Gumer to 0.83 ha in Wolmera district, and from 0.50 ha for ware potato producers to 0.64 ha for regular seed producers.

Results

Know-why of bacterial wilt of scientists

Bacterial wilt is a damaging potato disease, caused by *Ralstonia solanacearum* (Yabuuchi, 1995). The pathogen is categorized as seed-, soil- and water-borne since it spreads through the use of infected seed as planting material, infected soil, surface run-off and contaminated irrigation water (Elphinstone et al., 2005; Hayward, 1991; Janse, 1996). The pathogen can also be introduced to a crop field through contaminated farm tools when used for cultivation and weeding. Once the pathogen is established in a potato field, it can survive in the soil for many years and thus prohibits subsequent production of potato in that field (Denny et al., 1994; Hayward, 1991).

Ralstonia solanacearum is a widespread pathogenic bacterium that causes a wilt disease with severe effects on more than 200 host plant species which include many economically important solanaceous crops such as potato, tomato, eggplant, tobacco and chili (Elphinstone, 2005; Hayward, 1991). This bacterium enters the host plant roots, colonizes the xylem and makes the host plant collapse (Genin, 2010; Vasse et al., 2005). It has effective pathogenicity determinants to invade and colonize and destroy host plants. Visible symptoms of the infected plants are wilting, stunting and yellowing of the foliage. When the seed potato tuber is infected by this bacterium, the vascular ring decays and slime oozes are released from it until the tuber is completely destroyed (Vasse et al., 2005). After destroying the host plant, the bacterium is released to the environment and survives in soil, water or other host plants including weeds. It exhibits successful strategies for survival in harsh conditions through diverse survival forms until it contacts with a new host plant (Vasse et al., 2005; Hayward, 1991). The pathogen can also form latent infections, where host plants contain a bacterial population but without visible symptoms of infection (Aliye et al., 2015; Swanson et al., 2007; Priou et al., 2001). In Ethiopia, wide spreading of the disease has been found to be associated with latently infected seed distribution across the country (Abdurahman et al., 2017). The disease is also indigenous in many areas of the country.

Bacterial wilt is difficult to control essentially because of its diverse host plant species, its transmission through latent infection, the multitude of sources of infection, and long survival of the pathogen in the soil. Recent advances in control measures include chemical, biological, physical, phytosanitation and cultural practices (Yuliar et al., 2015). But chemical control has not been proven to be efficient to control bacterial wilt since the pathogen survives in deeper soil layers (Huet, 2014; Hayward, 1991). Also, chemicals have damaging effects on the environment. Likewise, even though studies have shown the potential value of some biological control agents, their suppression capacity is usually too low to be commercially used at large scale or requires high rates of inocula (Champoiseau et al., 2010; Whipps and Gerhardson, 2007). Physical methods like soil solarization using transparent plastic mulches have been proven to be effective against the pathogen although they are also difficult to be implemented by smallholder farmers (Yuliar et al., 2015). Thus, phytosanitation and cultural practices are the recommended and most widely used methods to eradicate or reduce bacterial wilt (Yuliar et al., 2015; Champoiseau et al., 2010). Phytosanitations include planting disease-free tuber seed on disease-free field, decontamination of farm tools, decontamination of irrigation water, diversion of surface run-off, and quarantine measures. Cultural practices include crop rotation of 5-7 years of excluding host plants, soil amendment, rogueing of plants with symptoms of bacterial wilt and burning them, destruction of host weeds, and removing and destroying rotten tubers and potato haulms by burning (Li and Dong, 2013; Lemaga et al., 2001a). Overall, several studies have proven that an integrated management strategy using a combination of phytosanitation and cultural practices is the most feasible approach to control bacterial wilt (Yuliar et al., 2015; Champoiseau et al., 2010; Lemaga et al., 2005). In addition, to effectively control the disease and prevent it from further spreading, a community-based approach is important through cooperation among farmers. The farmers need to make a concerted effort by practicing the cultural and phytosanitation measures to significantly control the disease in their community (Van de Fliert, et al., 1998; Pradhanang et al., 1993).

Know-why of late blight of scientists

Late blight of potatoes is also a devastating disease and it is caused by a fungus-like, microscopic oomycete pathogen *Phytophthora infestans* (Mont.) de Bary (Erwin and Ribeiro, 1996). This pathogen is predominantly dispersed aerially from one place to another and disseminates to healthy plant tissues via rain splash or on wind currents. *Phytophthora infestans* can infect and destroy all plant parts, including leaves, stems and tubers of potato plants (Cooke et al., 2011; Garrett et al., 2001; Erwin and Ribeiro, 1996). It grows and reproduces rapidly on the host plant and results in severe epidemics during conditions of high moisture and moderate temperatures (Coffey and Gees, 1991; Harrison, 1995).

Symptoms of late blight infection on potato leaves include blackish water soaked lesions, and whitish sporulation of the pathogen around the margin of the lesions (Arora et al., 2014; Erwin and Ribeiro, 1996). The symptoms usually begin near the edges or leaf tips and lesions expand quickly, turn dark brown, and damage the plant. Symptoms of late blight on potato stems are elongated and dark brown lesions while the disease results in irregular reddish brown coloured lesions on the surface of the tubers. At advanced stages of the disease, brown rot can be found on the tuber (Arora et al., 2014; Ingram and Williams, 1991).

Management methods for late blight include genetic, chemical, biological and cultural methods (Bouws and Finckh, 2008; Ke-qiang and Forrer, 2001; Struik et al., 1997). Genetic control method refers to the use of potato varieties having resistance to the pathogen that causes the disease. Resistance varieties stop or slow down the development of the disease (Kirk et al., 2005). Several potato varieties that are resistant to late blight are being produced in many countries including Ethiopia. Chemical control using fungicides that are capable of preventing infection or of slowing down the disease are also effective and constitute predominant late blight management methods. Broadly there are two kinds of fungicides, contact and systemic. Contact fungicides only protect plant area where fungicides are applied and plant leaves developed after application of the chemicals are not protected against the pathogen. But systemic fungicides are absorbed through the plant foliage or roots and they are capable to protect leaves formed after the application (Cohen and Coffey, 1986). Biological methods consist of reducing late blight infection by using live microorganisms that have antagonistic effects against *Phytophthora infestans* (Ke-qiang and Forrer, 2001; Struik et al., 1997). Practicality and effectiveness of biological methods are, however, uncertain in the context of smallholder farmers (Ke-qiang and Forrer, 2001). Cultural practices include scheduling planting time, use of early maturing cultivars, use of pre-sprouted seed tubers, destruction of volunteer potato plants, making high hills to avoid or reduce contact of tubers with sporangia coming from infected foliage, foliage cutting two to three weeks before harvesting, timely harvesting, and destruction of discarded tubers by safely burying or burning, among others (Cooke et al., 2011; Garrett et al., 2001).

With an integrated disease management approach of a combination of resistant varieties, fungicides and cultural practices late blight could be controlled with low dose and frequency of fungicides (Kirk et al., 2005). Furthermore, an integrated approach is more economical for smallholder farmers besides reducing environmental pollution (Kirk et al., 2005; Namanda et al., 2004). Moreover, cooperation among farmers is important for effective control of the disease by avoiding infection from sources of inoculum in the environment (Ortiz et al., 2009). Hence, similar to that of bacterial wilt, a community-based approach seems to be a promising strategy to reduce late blight severity. In the Ethiopian context, an integrated disease management approach has been adopted by the national research system as a strategy to control late blight. In this regard, about 30 late blight resistant potato varieties have been released over the last three decades and are now in production in different parts of the country (Berihun and Woldegiorgis, 2013). Nonetheless, the pathogen has developed new races and most of the varieties have become susceptible to late blight and the farmers are largely relying on application of fungicides (Shimelash, 2015). This makes the use of a combination of methods more compelling to effectively control the disease.

Know-why of bacterial wilt of farmers

The farmers in the study areas were unaware of the causal agent of bacterial wilt and gave different assumptions based on their personal opinions and/or from what they heard other farmers say. None of the farmers mentioned the cause of this disease to be a pathogen. The farmers provided different explanations and confused a causal agent of the disease with various environmental factors, ranging from water shortage, insects, and earthworms to planting high moisture content seed potato, and waterlogging (saturation of soil with water). Farmers who claimed that water shortage is the cause of bacterial wilt seemed to perceive it as a normal plant wilting from moisture stress. Waterlogging as a cause for bacterial wilt was particularly mentioned by farmers who were producing potato using irrigation.

The majority of the farmers (60%) did not know bacterial wilt spreading mechanisms. But 40% of the farmers reported that they knew how bacterial wilt spreads and described different methods they thought it spreads through. Among these farmers, 63% and 52% of them mentioned infected seed potato and infested soil, respectively. Only few farmers, 7%, pointed out contaminated farm tools as a means for the spread of the disease. But none of the farmers mentioned other bacterial wilt spreading mechanisms such as contaminated irrigation water, and infected alternative host plants. In addition, none of the farmers was able to recognize latent infection (symptomless transmission) of bacterial wilt.

Know-why of late blight of farmers

Concerning the causal agent of the late blight disease, 97% of the farmers associated it with abiotic factors like rainfall, humidity and cloud that rather are environmental conditions contributing to the development and spread of the pathogen that causes late blight. Only few farmers (3%), mentioned the cause of late blight to be microorganisms. This shows that the majority of the farmers, including producers of quality declared seed and of regular seed did not recognize the actual cause of late blight.

Almost none of the farmers recognized the methods by which late blight spreads from one area to another, even though few farmers mentioned it to be through infected seed. It is important to note that none of the farmers mentioned wind or water as a spreading mechanism for late blight. As such, the farmers did not consider neighboring potato farms as a source of infection, which can potentially influence farmers' practice in view of the need to collectively act to effectively combat the disease.

Know-what of bacterial wilt and its management methods of farmers

The majority of the farmers (72%) reported to know bacterial wilt, although not necessarily by its name. When the farmers were shown photographs of bacterial wilt symptoms on potato leaves and tubers without mentioning the name of the disease, most of the farmers recognized the symptoms as a problem they had in their potato fields or observed it in their neighborhood, both during *Belg* (short rainy season) and *Meher* (long rainy season) seasons. Overall, it was much easier for farmers to identify pictures of bacterial wilt symptoms on the leaves than on tubers. The farmers did identify general wilt of the potato plant. However, they did not recognize other common symptoms such as yellowing of foliage and stunting of the potato plant that can be associated with bacterial wilt. Statistically, there was a significant association between farmers' knowledge of the disease and their location/district (Table 2) with farmers in Wolmera Woreda relatively having better understanding of the disease (Pearson Chi-Square=81.136, $p<0.001$). But there was no statistically significant association between farmers' knowledge of the disease and the category of producers (Pearson Chi-Square = 1.309, $p= 0.520$).

Farmers' knowledge of different management methods for bacterial wilt was also limited. Among the farmers who reported to know bacterial wilt, most of them (84%) mentioned rogueing plants with symptoms of bacterial wilt as an effective management method for the disease (Table 3.2). Cultural management methods were mentioned only by a few farmers and included planting bacterial wilt free seed (28%), crop rotation (19%), and decontamination of farm tools (3%). Furthermore, about 7% of the farmers, mostly ware potato producers, mentioned chemical application as a management method for bacterial wilt (Table 3.2).

Table 3.2: Farmers' know-what of bacterial wilt management methods.

Bacterial wilt management options recognized by farmers	% within type of farmers*			% within districts*			% of total respondents (n=147)
	QDS (n= 22)	Seed (n=52)	Ware (n=73)	Gumer (n=11)	Doyogena (n=47)	Wolmera (n=89)	
Planting bacterial wilt free seed potato	41	40	15	9	30	29	28
Rogueing plants with symptoms of bacterial wilt	86	81	85	82	72	90	84
Crop rotation	59	21	6	9	40	9	19
Chemical application	0	4	11	18	11	3	7
Decontaminating farm tools	5	8	0	0	1	3	3

* Multiple answers were possible as most farmers reported more than one practice.

Know-what of late blight and its management methods of farmers

Similar to the case of bacterial wilt, during the survey, farmers were shown photos of late blight symptoms on potato leaves, stems, and tubers without mentioning anything about the disease. The majority of the farmers (94%) recognized the symptoms as a disease problem they had in their potato fields, mainly during the main rain season (*meher*). Again, similar to the case of bacterial wilt, the farmers more easily recognized the disease on potato leaves and stems than on potato tubers. Only few farmers, 6%, could not recognize late blight from the picture shown to them. All farmers in Wolmera district recognized the disease while 88% and 93% of the farmers in Gumer and Doyogena, respectively, identified the problem and there was a statistically significant association between farmers' understanding of the disease and their location/district (Pearson Chi-Square = 12.671, $p = p=0.002$). But there was no statistically significant association between farmers' knowledge of the disease and the category of producers (Pearson Chi-Square = 1.596, $p = 0.450$).

Overall, more than 92% of the farmers reported that fungicide application was an effective method to control late blight, with 100%, 94% and 89% representing producers of quality declared seed, regular seed and ware, respectively (Table 3.3). A significantly larger proportion of farmers in Gumer district (99%) reported fungicide application as a prominent method to control late blight compared with 85% and 93% of the farmers in Doyogena and Wolmera districts, respectively. About 25% and 11% of the farmers also reported use of late blight resistant potato varieties and cultural methods like early planting and crop rotation as effective late blight management methods, respectively.

Table 3.3: Farmers' know-what of late blight management methods.

Late blight management options recognized by farmers	% within type of farmers*			% within districts*			% of total respondents (n=246)
	QDS (n= 39)	Seed (n=81)	Ware (n=126)	Gumer (n=72)	Doyogena (n=71)	Wolmera (n=103)	
Chemical/fungicide application	100	94	89	99	85	93	92
Use of resistant varieties	46	25	20	18	28	29	26
Cultural methods (early planting and crop rotation)	5	14	10	4	11	15	11

* Multiple answers were possible as most farmers reported more than one practice.

Know-who: sources of information on bacterial wilt and late blight management

The majority of the farmers (68%) mentioned that they had received some information on bacterial wilt and late blight from different sources. Among these farmers, the majority of them were QDS producers (93%), followed by regular seed producers (72%), and ware producers (58%). Statistically, there was a significant association between farmers who received some kind of information on the diseases and the type of farmers (Pearson Chi-Square = 16.670, p=<0.001). Furthermore, the majority of the farmers in Wolmera district (84%) got access to information compared to 61% and 54% of the farmers in Gumer and Doyogena districts, respectively; there was a statistically significant association between farmers who got information on the diseases and their districts (Pearson Chi-Square = 20.057, p=<0.001). This variation among the study districts may be due to the presence and operation of the Holeta Agricultural Research Centre in Wolmera district for more than three decades.

Of the farmers who got information on the two diseases, most of them (64%) mentioned extension workers as the main source of information followed by fellow farmers (42%), non-governmental organizations (NGOs) (22%), agricultural researchers (19%) and seed producer cooperatives (11%). This seems to indicate that extension workers and other fellow farmers are the most important sources of information on potato diseases for the farmers in the study districts. On the other hand, almost equal proportions of QDS producers (32%) and regular seed producers (31%) reported NGOs as important sources of information, whereas only 9% of ware producers mentioned NGOs as an information source. This is explained by the considerable support that NGOs provide to seed producers in major potato growing districts in the country. Also, about 33% and 24% of regular seed and QDS producers, respectively, reported agricultural researchers as a source of information compared with only few ware potato producers (5%). This seems to suggest that seed producers are more likely to be targeted by agricultural researchers than ware potato producers.

Among the farmers who got some kind of information on bacterial wilt and late blight, most of them (83%) got information on management methods of the diseases followed by their symptoms (41%), their causes (28%) and modes of spread (22%) (Table 3.4). Relatively, more QDS farmers (54%) and regular seed producers (33%) got information on the causal agents of the diseases compared with only 11% of ware potato producers (Table 3.4). Thus, the farmers got much less information about know-why of the diseases. This seems to be the reason why sometimes most farmers did important things like crop rotation but not for disease management purpose. Likewise, more producers of QDS (46%) and regular seed (25%) acquired information on modes of spread of the diseases while only 9% of the ware producers reported acquiring information on the same topic. Overall, the reason why most farmers reported getting more information on management methods than other generic aspects of the diseases seems to suggest that the information sources usually give more focus to management methods of the diseases than their causal agents and spreading mechanisms.

Table 3.4: Kind of information that farmers received on bacterial wilt and late blight.

Bacterial wilt management options recognized by farmers	% within type of farmers			% within districts			% of total respondents (n=157)
	QDS (n= 37)	Seed (n=61)	Ware (n=81)	Gumer (n=50)	Doyogena (n=43)	Wolmera (n=86)	
Management methods	86	82	78	68	91	88	83
Spreading mechanisms	46	25	9	22	40	13	22
Mode of diagnosis	60	46	28	40	44	40	41
Causes	54	33	11	36	42	15	27

Know-how: farmers' management practices of bacterial wilt and late blight

In this section, a variety of farmers' practices of bacterial wilt and late blight management are presented considering the role of knowledge in these practices. Some practices are specific to each kind of disease while others are common to both diseases as described in the following section.

Practice of crop rotation

Most of the farmers (95%) reported growing potato in rotation with cereals, pulses or other vegetables, with all QDS producers and regular seed producers practicing it. The few farmers (5%), who reported not practicing crop rotation, were all ware potato producers. Statistically, farmers' practice of crop rotation was significantly associated with the category of the farmers (Pearson Chi-Square = 12.575, p=<0.002) but not with location/district of the farmers (Pearson Chi-Square = 5.647, p=<0.059).

In relation to the length of crop rotation, nearly half of the farmers (48%) commonly practiced a one-season interval, with only 13% of the farmers practicing a three-season interval (Table 3. 5). But the number of seasons of crop rotation was significantly associated with the type of farmers (Pearson Chi-Square = 12.575, p= 0.002), with quality declared seed farmers relatively practicing more seasons of crop rotation than regular seed producers and ware producers. Twenty-eight percent of QDS producers, 38% of regular seed producers and 61% of QDS producers practiced only a one-season interval of crop rotation (Table 3.5). About 26% of QDS producers practiced a three-season interval of crop rotation compared to 15% and 8% of regular seed and ware producers, respectively.

Generally, most farmers considered benefits of crop rotation in view of improving soil fertility to avoid yield reduction due to plant nutrient depletion from the soil. They did not fully recognize the role of crop rotation for controlling soil-borne diseases such as bacterial wilt. As a result, many farmers practiced a one-season interval of crop rotation, which is an ineffective practice for disease management. This is further evidenced by only 19% and 11% of the farmers who reported crop rotation as a management practice for bacterial wilt and late blight, respectively, as pointed out in Sections 3.4.4 and 3.4.5. Furthermore,

Table 3.5: Kind of information that farmers received on bacterial wilt and late blight.

	% within type of farmers			% within districts			% of total
Number of seasons	**QDS (n= 39)**	**Seed (n=85)**	**Ware (n=124)**	**Gumer (n=75)**	**Doyogena (n=97)**	**Wolmera (n=97)**	**respondents (n=248)**
One season	28	38	62	57	32	55	48
Two seasons	41	47	30	31	53	31	38
Three seasons	26	15	8	12	13	15	13
More than three seasons	5	0	0	0	3	0	1

the survey revealed that none of the regular seed and ware potato producers practiced crop rotation for more than a three-season interval while only 5% of the QDS farmers applied the practice for more than three seasons (Table 3.5).

Practice of seed potato renewal

Renewal of seed potato is not a common practice among the majority of all type of farmers in the study areas. Only 13% of the farmers, the majority of whom were quality declared seed producers or regular seed producers, renewed seed potato during the last five years. Other farmers had been planting potato for an unspecified number of generations without changing it. Particularly, ware potato producers seemed to be less experienced in seed potato renewal. They did not know the generation of their seed potato as they had been using the same seed for over many generations. They usually retained seed for the next planting season from their previous harvest or bought it from the local market. Many farmers had a general understanding that productivity declines if the same seed is used over and over without being renewed. However, they did not associate it with management of seed-borne diseases like bacterial wilt and late blight. It was not common to hear farmers associating the benefit of seed renewal with disease management. This is also evident from the low percentage of farmers (Tables 3.4 and 3.5) who mentioned seed related attributes ('planting clean seed' for bacterial wilt and 'resistant varieties' for late blight) as management options. On the other hand, those few farmers who knew the contribution of seed renewal to disease management, did not necessarily renew their seed due to very limited supply of basic seed and high price which hindered the farmers from practising seed renewal.

Overall, only 13%, 9% and 15% of producers of QDS, regular seed, and ware, respectively, used new seed potatoes within the last five years. Producers of QDS and regular seed who reported to renew their seed had purchased basic seed from agricultural research centers. However, ware potato producers just bought seed potato of unknown origin from local market or neighbor farmers, which had been recycled for a number of generations. It is important to note that this practice of renewal of ware producers is not effective to prevent diseases from spreading, even though a considerable number of them claimed to renew their seed potatoes. Statistically, there was not a significant association between the practice of renewing seed potatoes and the farmers' category (Pearson Chi-Square = 1.328, p=<0.515), or their district (Pearson Chi-Square = 3.307, p=<0.191).

Practice of handling infected/damaged seed and ware potatoes at harvest

Nearly all farmers (97%) reported sorting as a practice to separate infected/damaged potato from healthy looking ones at harvest. Usually, the farmers tried to sort both infected/damaged seed potato tubers and ware potato from healthy looking ones through visual observation. When asked what they did with infected/damaged potato tubers, about 42% of the farmers reported that they would leave them on the field, of whom 8%, 39% and 54% were QDS producers, regular seed producers, and ware producers, respectively. On the other hand, nearly 30% of the farmers reported that they would collect and bury infected/damaged potato tubers sorted during harvesting, whereas about 19% of the farmers would throw infected/damaged potato tubers away at the farm side (Table 3.6). Only 3% of the farmers reported collecting and burning of the infected/damaged potato tubers. Thus, only few farmers properly disposed diseased/damaged seed potato and some farmers even thought that leaving infected/damaged potato tubers on the field would improve soil fertility with little regard for possible contamination of the soil by potato diseases like bacterial wilt. Their current practice of handling infected/damaged potato tubers contributed more to the spread of the diseases rather than controlling them. Most farmers did not know the importance of sorting infected/damaged potatoes at harvest from the perspective of controlling bacterial wilt and late blight. They did sorting mainly to separate and dump rotten or damaged potato tubers from healthy looking ones before home consumption, marketing or storing for seed. Furthermore, referring back to farmers' knowledge of effective management methods of the two diseases (Tables 3.2 and 3.3), sorting diseased seed potato was not among the few management options known to many farmers.

Table 3.6: Farmers' practice of sorting out infected/damaged seed and ware potato at harvest.

What farmers do with infected/ damaged seed and ware potatoes	% within type of farmers*			% within districts*			% of total respondents (n=147)
	QDS (n= 22)	Seed (n=52)	Ware (n=73)	Gumer (n=11)	Doyogena (n=47)	Wolmera (n=89)	
Leave on the field	8	39	54	33	24	63	42
Collect and burn	0	4	4	5	0	4	3
Collect and burry	43	39	20	23	42	26	30
Throw away at farm side	20	13	22	14	30	14	19
Use as livestock feed	50	21	15	38	21	11	22

* Multiple answers were possible as most farmers reported more than one practice.

The majority of the farmers (80%) mentioned that they applied the practice of rogueing potato plants with symptoms of bacterial wilt infection as a management method. Among these farmers, 68%, 81% and 82% were producers of QDS, producers of regular seed and producers of ware, respectively. There was significant association between practice of rogueing and study districts (Pearson Chi-Square=15.388, $p<0.001$). A significantly larger proportion of farmers in Wolmera district (90%), reported practicing rogueing of potato plant with symptoms of bacterial wilt as one of the methods to manage bacterial wilt, while 73% and 62% of the farmers in Doyogena and Gumer districts, respectively, pointed out the same method. These farmers usually removed infected potato plant with visible symptoms and threw them at the farm side or in ditches. But such practice has a striking implication for spreading of the disease instead of controlling it. Thus, farmers' current practice of rogueing plants with symptoms of bacterial wilt is not effective mainly due to lack of knowledge among farmers on the spreading mechanisms of the disease. Furthermore, about 26% of the farmers reported to practice planting bacterial wilt free seed potato. Farmers that reported planting seed free from bacterial wilt infection, usually tried to visually confirm whether seed potato was infected or not, without understanding and considering the possibility of latent infection of seeds. Thus, they thought that clean seed potato can be distinguished from infected seeds through visual observation. Forty-two percent of QDS producers and 39% of regular seed producers mentioned using seed free from bacterial wilt compared with only 15% of ware producers. Nonetheless, availability of bacterial wilt free seed is questionable given the current prevalence of the disease, latent infection of the pathogen that causes the disease, and lack of a standard seed certification scheme based on laboratory testing in the country. Also, some farmers reported that they applied chemicals expecting that these chemicals could suppress bacterial wilt. As there is no chemical that can help control bacterial wilt on the market, it seems that they applied chemicals like fungicides or pesticides, which further indicates the lack of know-how among these farmers.

Practice of fungicide application

More than 87% of the farmers reported practicing fungicide application to manage late blight. The majority of quality-declared seed producers (97%) reported to practice fungicide application to control late blight as was the case for regular seed producers (91%) and ware potato farmers (82%). Statistically, there was a significant relationship between fungicide application and the category of farmers (Pearson Chi-Square= 6.569, $p = 0.015$). But there was no significant relationship between farmers' practice of fungicide application and their district (Pearson Chi-Square= 3.028, $p = 0.220$), with 89%, 82%, and 90% of farmers in Gumer, Doyogena and Wolmera districts, respectively, practicing fungicide application to control late blight.

Most farmers reported applying fungicides they got from private vendors or cooperative unions without understanding the efficacies of the fungicides and without choosing which product to use. They also did not understand late blight pressure in the surrounding and they simply applied when they observed the symptoms of late blight infection. Further, the farmers did not understand the importance of collaboration with neighbor farmers to reduce the inoculum pressure in the area. The most commonly used fungicides in the study sites were Ridomil and Mancozeb, while many farmers were not able to differentiate between the two kinds of fungicides. Most of the farmers reported to apply three to five times per season, depending on the severity of the disease and availability of fungicides. In this regard, the dosage and frequency of applications were questionable given farmers' limited know-how of appropriate fungicides application practices.

Furthermore, during key informant interviews, all farmers mentioned that the farmers applied fungicides individually when the disease occurred without being aware of the importance of collective action to reduce the inoculum of the pathogen from their respective area. In many instances, ware potatoes and seed potatoes were planted in neighboring fields, but the farmers practice different time and frequency of fungicide applications.

Practice of using late blight resistant potato varieties

Potato growers in all the three districts tended to grow improved potato varieties, with the majority of the farmers (66%) producing improved varieties only. Across all the three districts, few farmers (10%) grew local varieties only, and all of them were ware potato producers, whereas nearly 25% of the farmers produced both local and improved varieties. Relatively, more farmers in Wolmera district (83%) were growing improved varieties only, compared with 50% and 61% of the farmers in Gumer and Doyogena districts, respectively, (Table 3.7).

The majority of the farmers (100% of QDS producers, 97% of regular seed producers, and 87% of ware producers) reported Gudane as the dominant potato variety they were growing. Overall, three popular potato varieties, Gudane, Belete and Jalene were grown by 92%, 45%, and 33% of the farmers that reported growing improved varieties, respectively (Table 8). These improved varieties were released by Holeta Agricultural Research Center (HARC) primarily as late blight resistant. But the farmers reported that particularly Jalene variety became highly susceptible to late blight, which might be due to seed degeneration as the farmers have been continuously growing this variety since it was released in 2002 and its resistance could be broken by the pathogen. On the other hand, Belete variety was grown by 87%, 45% and 29% of producers of QDS, regular seed, and ware, respectively (Table 3.8). Even though Belete variety has been the most recent of the potato varieties released by the national research system, it has also become susceptible to late blight and farmers do not grow it without repeated application of fungicides. In relation to using late blight resistant potato varieties, farmers have better understanding of the importance of resistant varieties. However, since the existing potato varieties have become susceptible to late blight, farmers did not rely on this practice alone as an effective management method.

Table 3.7: Type of potato varieties grown by farmers in the study sites.

Type of potato varieties	% within type of farmers			% within districts			% of total respondents (n=261)
	QDS (n= 40)	Seed (n=85)	Ware (n=136)	Gumer (n=82)	Doyogena (n=76)	Wolmera (n=103)	
Local varieties only	0	0	18	4	18	8	10
Improved varieties only	90	73	54	50	61	83	66
Both improved and local varieties	10	27	27	46	21	10	25

Table 3.8: Improved potato varieties grown by farmers in the study sites .

Major improved potato varieties grown	% within type of farmers*			% within districts*			% of total respondents (n=236)
	QDS (n= 40)	Seed (n=85)	Ware (n=111)	Gumer (n=79)	Doyogena (n=62)	Wolmera (n=95)	
Gudane	100	97	87	87	97	93	92
Jalene	33	42	26	52	16	28	33
Belete	87	45	29	46	42	45	45
Guassa	0	6	15	17	0	10	9
Other improved varieties	5	2	6	6	0	6	5

* Multiple answers were possible as most farmers reported more than one potato variety.

Use of mobile phone among farmers

Most of the farmers in the study sites (73%) owned a mobile phone, of whom only about 2% of the farmers had smart phones. The highest rates were reported from Wolmera district (82%), while in Doyogena and Gumer districts 72% and 62% of farmers owned mobile phones, respectively (Fig. 3.1). On the other hand, among the farmers who owned mobile phones 81% of the farmers were regular seed producers, followed by 73% and 68% of the farmers who were producers of QDS and ware, respectively (Fig. 3.2). Further, about 45% of the farmers who had a mobile phone were between 18 and 35 years, while only 12% of the farmers who had mobile phones were above 56 years. This signifies that younger farmers were more likely to own mobile phones. Furthermore, 82% of the farmers who owned a mobile phone attended either primary or secondary schools while only 8% of the farmers who had mobile phones were illiterate.

During key informant interviews, the farmers described as they used mobile phones to communicate various social issues with their family members, relatives, and other farmers in their community. In addition, the farmers used mobile phones to communicate with agricultural extension workers, district level agricultural experts, agricultural researchers and cooperative officers mainly to check availability of agricultural inputs, arrange meetings and/or field visits, access market information, and report agricultural problems, among others.

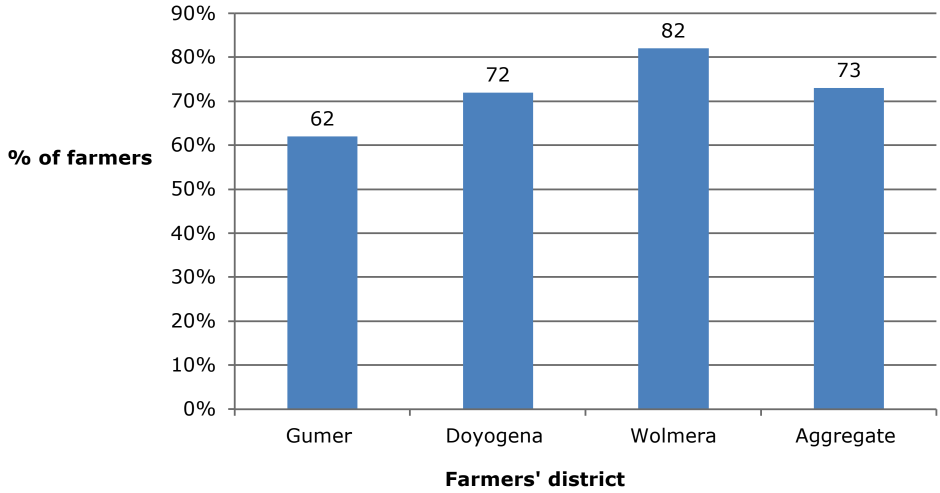


Figure 3.1:

Mobile phone use by farmers' district .

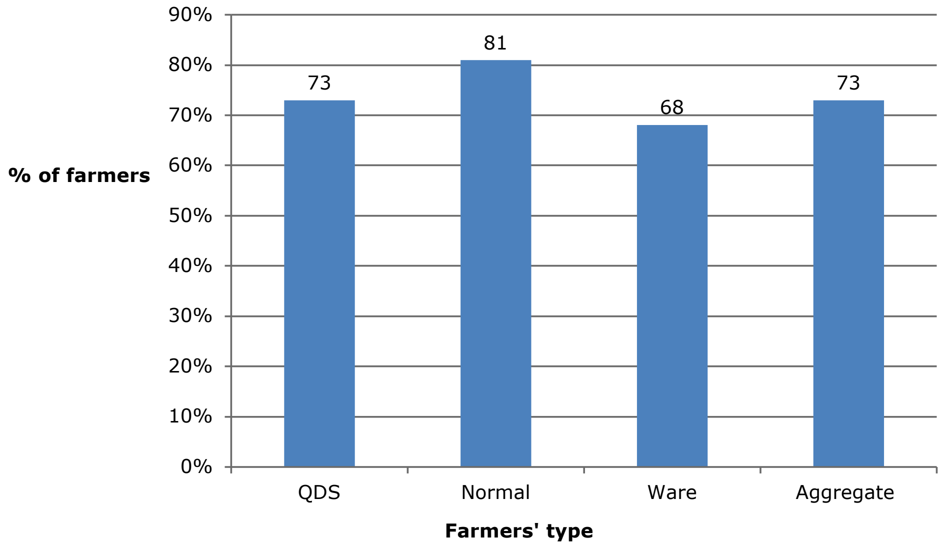


Figure 3.2:

Mobile phone use by farmers' type.

Discussion

This diagnostic study was designed to examine whether farmers' knowledge of the two major potato diseases, bacterial wilt and late blight, and their management methods hinders or contributes to effective disease management practices. The findings provide relevant insights regarding the requirements for developing an intervention strategy for smallholder potato farmers in Ethiopia. In order to be effective, such strategy 1) has to be community-based because of the spreading mechanisms of the diseases, and 2) needs to combine cultural practices with phytosanitary measures, according to recent insights (Yuliar et al., 2015; Champoiseau et al., 2010; Lemaga et al., 2005).

Knowledge of farmers about bacterial wilt and late blight

The study findings show that all the groups of farmers evidently had limited know-why, know-what, know-who, and know-how of the two diseases, when mirrored to scientists' understanding of the diseases. None of the farmers recognized the cause of bacterial wilt to be a pathogen. Rather, the farmers erroneously reported the cause to be unrelated factors such as shortage of water, insects, earthworms, and waterlogging. Likewise, most farmers did not know the cause of late blight. They associated a causal agent of late blight to be abiotic factors like rainfall, humidity and cloud. This finding is consistent with that of Nyankanga et al., (2004) who reported that most of the potato farmers in Kenyan highlands associated late blight with weather conditions. Although not fully accurate, this is relevant knowledge, because such environmental conditions favor the development of the pathogen that causes the disease (Mizubuti et al., 2000; Mizubuti and Fry, 1998).

Unlike the causal agents of the diseases, most farmers could recognize the symptoms of both bacterial wilt and late blight on leaves and stem. But the majority of the farmers could not recognize the visible symptoms of the diseases on the seed tubers. While a considerable number of farmers (40%) correctly mentioned infected seed and soil to be mechanisms through which bacterial wilt spreads, they could not act upon this knowledge. Moreover, none of the farmers knew about the latent (symptomless) infection of bacterial wilt and hardly any of them was aware of the other spreading mechanisms of bacterial wilt like infected host plants, contaminated irrigation water and contaminated farm tools (Genin, 2010; Janse, 1996; Hayward, 1991). This limited know-why has an essential implication for the prevalence and management of bacterial wilt (Genin, 2010; Hayward, 1991). Without a good understanding of its various spreading mechanisms, it is difficult to effectively control the disease.

Regarding late blight, none of the farmers were aware of the spreading mechanisms of late blight. But, since the pathogen that causes late blight is mainly airborne and largely disperses by wind (Lima, et al., 2009), farmers should be aware that they can be affected by the practice of other farmers in neighboring fields. The finding signifies that farmers may think that their potato field is safe, despite the occurrence of the diseases in their neighbors' fields. Moreover, as a consequence, they seem not to recognize the importance of concerted effort to deal with the diseases.

Producers of ware potato reported agricultural extension workers and fellow farmers to be the most important sources of information on bacterial wilt and late blight management. In contrast, agricultural research centers and NGOs were reported by both QDS and regular seed producers as major sources of information on the diseases. This finding aligns with the considerable support that agricultural research centers and NGOs provide to seed producers in the country. There are however, no differences in knowledge about causes and spreading mechanisms between ware potato producers and (both kinds of) seed producers. The only significant difference between the groups concerns the know-what of crop rotation and fungicide application. There are also very few differences between the districts; in the district with an agricultural research centre in the area, more farmers recognized the diseases and practiced rogueing.

The overall lack of knowledge regarding causes and spreading mechanisms of bacterial wilt may be explained by the fact that it has only recently become a severe problem (Abdurahman et al., 2017; Gorfu et al., 2013) and development initiatives have not yet given due attention to the disease (Gorfu et al., 2013). The lack of knowledge regarding late blight is rather surprising because it has been the major potato disease in Ethiopian potato production systems for many years and the farmers have been receiving different forms of supports to deal with the disease. A possible explanation for this is that the efforts to increase farmers' knowledge did not include all relevant learning approaches that are related to the different forms of knowledge. Know-what and know-why are learned through reading and attending trainings while know-how and know-who can be learned mainly through experiential learning and in social interaction (Lundvall, 1992). This research, as well as other reports, indicates that many seed potato producers were trained in potato production and disease management practices in the country (CIP, 2016, 2013), which emphasizes particularly the know-what. Therefore, the current limitations regarding the other categories of knowledge underlines the need for supporting the farmers to learn through a combination of appropriate approaches.

The know-why could be increased via for instance a training about the causes and spreading mechanisms of the pathogens for both bacterial wilt as well as late blight. Diagnostic tools or kits combined with tailor-made advices may help to effectively diagnose and visualize the pathogens and stimulate the farmers to take action. In addition to these well-known classic methods, the sharing of information about the prevalence of the disease may contribute to the know-what of farmers. In addition, it is crucial to provide farmers the room to generate the know-who and know-how for the management of both diseases. As these local forms of knowledge can only be generated by farmers themselves in the local context experiential learning, and social interaction should be stimulated.

The focus on seed producers in previous knowledge dissemination efforts may appear to be reasonable given the limited supply of quality seed in the country (Schulz et al., 2013; Hirpa et al., 2010; Gildemacher et al. 2009b). But in view of an effective disease management effort, QDS and regular seed producers may not succeed in controlling the diseases if ware producers' practices continue to increase disease inoculum in their surroundings. Therefore, for effective management of both diseases, this finding indicates the importance of involving ware producers in learning interventions.

Farmers' practices related to their knowledge

The findings of the study indicate that all three categories of farmers had better know-how of effective management methods for late blight such as use of fungicides and resistant potato varieties than for bacterial wilt.

For bacterial wilt, the dominant management practice reported by all categories of farmers was rogueing of plants with symptoms of disease infection. But this practice alone is not effective in controlling the disease if it is not combined with other cultural practices like crop rotation, soil amendment, and phytosanitation. This study also found that the farmers were just uprooting and throwing the infected plants away at the farm side or in ditches which could have serious implications for spreading the disease instead of controlling it. This further confirms that the know-how of the farmers is limited. Unexpectedly, QDS producers also reported the same practice which makes the practicality of the zero-tolerance level of bacterial wilt that currently stipulated in the QDS scheme questionable (ESA, 2015) and has striking implications for the quality of seeds produced by these group of farmers. Some farmers also mentioned the use of quality seed to control bacterial wilt. However, given the current prevalence and embedding of the disease in the country's seed system (Abdurahman et al., 2017; CIP, 2016; Gorfu et al., 2013) and due to a lack of formal seed certification system in the country (Schulz et al., 2013; Hirpa et al., 2010; Gildemacher et al., 2009b), the seed potatoes that the farmers receive may be infected with bacterial wilt. In addition, farmers' practice of crop rotation was found to be ineffective from the perspective of bacterial wilt control. They mostly practice one-season interval of crop rotation while the requirement for QDS producers is at least three seasons of rotation with non-host plants (ESA, 2015) and five to seven years of crop rotation are recommended for effective elimination of the inoculum from infested soil. Also the farmers did not renew seed potatoes for many years and they continued to plant seed potatoes of unknown generations and none the farmers, not even most QDS producers, could tell the generation of seed potato they were planting. Particularly, for producers of ware potatoes who mainly use farm saved seeds as planting material, this practice coupled with short interval of crop rotation increases *Ralstonia solanacearum* build up in their potato fields.

Regarding late blight, most of the farmers (87%) practiced application of fungicides. However, the farmers did not recognize what type of fungicides (contact or systemic fungicides) to use and when to apply. Farmers did not apply fungicides before they observed the first symptoms of late blight on the potato plant, which is ineffective in controlling the disease as the pathogen spreads quickly. Despite the availability of various decision support systems (DSS) that can help farmers optimising the use and timing of fungicide applications in developed countries (Shtienberg, 2013; Wharton et al., 2008), so far none of them has been introduced to Ethiopia. The farmers still spray fungicides in a conventional way and hence often with limited success in controlling the disease.

These findings show that the farmers' practices are somewhat informed by know-what of disease management: the majority of the farmers applied some crucial management strategies such as application of fungicides for late blight control, rogueing of plants with symptoms of bacterial wilt infection, and planting late blight resistant potato varieties for disease management reasons. Their knowledge is however too limited to apply these measures in an effective way. This stresses the conclusion above, that additional know-how is necessary to perform these practices effectively for disease management purpose. Moreover, some other practices that are also relevant for management of the diseases (like crop rotation, and sorting of infected potatoes) were undertaken for other than disease management reasons. This indicates that additional know-why may increase the value of these practices for farmers and stimulate them to understand their multiple functionality. It, hence, seems useful to develop a learning approach in which the know-why is locally generated and embedded and integrated with the know-what.

Implications for a community-based intervention and monitoring approach

The finding of this study has important implications for the development of a community-based approach to effectively deal with bacterial wilt and late blight in Ethiopian potato production systems.

Addressing the above mentioned limitations of farmers' knowledge is imperative for effective disease management. That is, the farmers need to learn about different aspects of the diseases including, causes, diagnosis methods, spreading mechanisms, effective management methods and how to integrate these into their daily practice, and importance of concerted effort, among others. To learn to manage the diseases in an effective way the conventional methods of training and instructing farmers may not suffice. In order to stimulate the development of all relevant forms of knowledge, farmers themselves need to be stimulated to generate and revise local knowledge in an experiential and interactive learning approach.

Such learning to do things differently is a process (Beers, et al., 2016) that needs to be integrated into the community-based strategy. A good start for stimulating farmers to be openly involved in such a learning process may be to raise their awareness of the interdependency among them in the local area. A relevant second step may be to define what concerted action may lead to quick improvement in this area and how monitoring would help them to recognize the effectivity of the farmers actions. What combination of measures fits in the cultural and ecological context of a specific community can be investigated in this way by farmers and experts. This exploration may stimulate the farmers to undertake these concerted actions.

Further, for the community-based intervention to be enabled, enforced and evaluated, an institutional arrangement at community level may be important (Ostrom, 1990). That is, the farmers can mutually agree on operational standards of what should be done and should not be done, from the perspective of disease management specifically and potato production more generally.

For bacterial wilt, the following phytosanitary and cultural management practices could, for instance, be integrated and stipulated in the bylaws as operational standards:

- Practicing crop rotation with non-host plants and with appropriate rotation length;
- Rogueing and burning potato plants with symptoms of bacterial wilt infection;
- Eradicating host weeds from potato fields and irrigation canals;
- Decontaminating farm tools before using for potato cultivation and harvesting;
- Making diversion ditches to prevent surface run-off from infected field

Similarly, for late blight, the following management practices could be translated into operational standards to be confirmed by the farmers.

- Applying the right dose and type of fungicides at the appropriate time;
- Cutting foliage two to three weeks before harvesting;
- Destroying volunteer potato plants that can be sources of late blight inoculum;

If the farmers have come to an agreement, it is important to track to what extent farmers are changing their practices in line with the operational standards. An ICT-based platform may support monitoring of the community-based intervention and disease occurrence. A first function of an ICT-based platform hence would be to monitor and account for their practices towards one another. Additional purposes of a platform could be 1) early warning of prevalence and spreading of the disease; 2) provision of contextualized advices; 3) provision of generic information; 4) evaluation of practices; by investigating which practices seem most effective, practical and affordable and why to be able to change direction if needed.

The platform could make use of mobile phones, since the study shows that the majority of the farmers in the study sites were using these devices to communicate on various social issues and access different kinds of information. This result is consistent with the findings of Agricultural Transformation Agency (ATA) (ATA, 2013) that reported rapid expansion of mobile phone use in Ethiopia and seems to suggest that mobile phone can be tapped into for bacterial wilt and late blight diagnosis and management in the study sites. Several studies have also reported the potential role that mobile-based platforms can play for agricultural development in many developing countries (Asenso-Okyere and Mekonnen, 2012; Aker, 2011). Mobile-based technologies such as voice call, Short Message Service (SMS) and Interactive Voice Response (IVR) are commonly considered more appropriate and promoted for agricultural information sharing and enabling collective action in smallholder farmers context in many developing countries (Asenso-Okyere and Mekonnen, 2012; Aker, 2011) . Similarly, some mobile-based initiatives have been implemented in Ethiopia by the ATA and the Ethiopian Commodity Exchange (ECX) to support agricultural extension service and provide market information, respectively (Meijerink et al., 2014; ATA, 2013).

On the basis of this study, we surmise that mobile phones can have an added value in the process of information sharing in a community-based approach and potato farmers can learn about effective disease management methods through SMS, voice call or IVR. Disease occurrence can also be possibly monitored and exchanged in these ways. Specifically for late blight, mobile phone can serve as a means for timely information sharing among farmers regarding the occurrence of the disease and for receiving timely information on when to apply fungicides based on proper prediction of disease occurrence. Practices could be reported and summaries of achievements can be shared via the phones. A platform needs to be developed in order to be able to collect and interpret data regarding both diseases, for the exchange of information among the farmers, for the development of advice, et cetera. But, it is important to consider farmers' need and context as such platforms can be constrained by many factors like network interruptions in rural areas and costs of communication.

In sum, it seems that a mobile-based platform can leverage a community-based intervention for effective bacterial wilt and late blight management in the study sites. Such monitoring would serve three goals:

1. Stimulate a learning process in which know-why, know-what, know-how and know-who become closely connected and adapted to the local context, by reflecting on what works and what does not work in the specific context and change the standards accordingly;

2. Stimulate collective action, by increasing trust among farmers and show that their efforts are worthwhile and sanction free-riders;

3. Connecting professional expertise of agricultural extensionists and researchers with farmers in need for advice in specific situations.

Conclusion

The study has provided new insight into farmers' knowledge of bacterial wilt and late blight in Ethiopian potato production systems. The study has indicated that farmers have limited know-what and know-why as well as know-who and know-how to effectively deal with the diseases in their specific local context. Regarding the first two types of knowledge, there were significant incongruences between scientific explanations and farmers' understanding of the diseases and practices to deal with them. Further, the study has shown that farmers' practices contribute to the spreading of the diseases rather than effectively manage them due to a lack of relevant and applicable knowledge among farmers. Previous extension efforts have not had the desirable effect although farmers had relatively better know-what and know-how of late blight than bacterial wilt.

Overall, given the current prevalence of the diseases and their diverse spreading mechanisms, there should be an emphasis for a community-based approach with due consideration of the social and biophysical dimensions of the diseases. The proposed community-based approach should comprise four basic elements 1) interactive learning, 2) combination of effective management practices (phytosanitation and cultural practices), 3) bylaws and 4) monitoring by leveraging mobile-based technologies on a digital platform. Farmers' knowledge of the diseases, which informs their management practices, needs to be enhanced in a learning approach that integrates generic and local knowledge. Moreover, the farmers need to act collectively and integrate several management practices in their efforts towards dealing with each disease. To enable a collective action among the farmers, community-based bylaws with mutually agreed upon operational standards can be a good institutional arrangement. Appropriate mobile-based technologies such as voice call or SMS can support the monitoring of the changes in farmers' practices and the prevalence of the disease.

References

ATA, 2013. Enhancing Farmer-Info-Services in Ethiopia: A Critical Review of Sources, Channels and Formats. (Addis Ababa, Ethiopia).

Abdurahman, A., Griffin, D., Elphinstone, J., Struik, P.C., Schulz, S., Schulte-Geldermann, E., Sharma, K., 2017. Molecular characterization of Ralstonia solanacearum strains from Ethiopia and tracing potential source of bacterial wilt disease outbreak in seed potatoes. Plant Pathol. 66, 826–834.

Aker, J.C., 2011. Dial A for agriculture: a review of information and communication technologies for agricultural extension in developing countries. Agric. Econ. 42, 631–647.

Aliye, N., Dilbo, C., Pillay, M., 2015. Understanding reaction of potato (Solanum tuberosum) to Ralstonia solanacearum and relationship of wilt incidence to latent infection. J. Phytopathol. 163, 444–455.

Arora, R., Sharma, S., Singh, B., 2014. Late blight disease of potato and its management. Potato J. 41.

Asenso-Okyere, K., Mekonnen, D.A., 2012. The Importance of Icts in the Provision of Information for Improving Agricultural Productivity and Rural Incomes in Africa, African Human Development Report. UNDP Sponsored Research Series.

Beers, P.J., Van Mierlo, B., Hoes, A.-C., 2016. Toward an integrative perspective on social learning in system innovation initiatives. Ecol. Soc. 21.

Beresford, R., 2007. The epidemiology of plant diseases. In: Cooke, B.M., Gareth Jones, D., Kaye, B. (Eds.), Plant Pathology, pp. 337–338 (56).

Berihun, B., Woldegiorgis, G., 2013. Potato research and development in Ethiopia: achievements and trends. Pages 35–44 in: seed potato tuber production and dissemination: experiences, challenges and prospects. In: Woldegiorgis, G., Berihun, B., Schultz, S. (Eds.), Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination, 12–14 March 2012. Bahir Dar, Ethiopia.

Bouws, H., Finckh, M., 2008. Effects of strip intercropping of potatoes with non-hosts on late blight severity and tuber yield in organic production. Plant Pathol. 57, 916–927.

Brown, V.A., Harris, J.A., Russell, J.Y., 2010. Tackling Wicked Problems Through the Transdisciplinary Imagination. Earthscan, London, UK.

Burdon, J.J., Barrett, L.G., Rebetzke, G., Thrall, P.H., 2014. Guiding deployment of resistance in cereals using evolutionary principles. Evol. Appl. 7, 609–624.

CIP, 2011. Roadmap for Investment in the Seed Potato Value Chain in Eastern Africa. (Lima, Peru).

CIP, 2013. Wealth creation through integrated development of the potato production and marketing sector in Kenya, Uganda, and Ethiopia, final report. J. Plant Pathol.

CIP, 2016. 12th Six-Month Program Report. Better Potato for Better Life Project. (Addis Ababa, Ethiopia).

CSA, 2012. The Federal Democratic Republic of Ethiopia, Central Statistical Agency, Agricultural Sample Survey, 2011/2012. (Addis Ababa, Ethiopia).

CSA, 2016. (Central Statistical Agency). Agricultural Sample Survey Report on Area, Production and Farm Management Practice of Belg Season Crops Private Peasant Holdings Vol. V Statistical Bulletin, Addis Ababa, Ethiopia.

Champoiseau, P., Jones, J., Momol, T., Pingsheng, J., Allen, C., Norman, D., Harmon, C., Miller, S., Schubert, T., Bell, D., 2010. Ralstonia Solanacearum Race 3 Biovar 2 Causing Brown Rot of Potato, Bacterial Wilt of Tomato and Southern Wilt of Geranium. American Phytopathological Society, Madison. Available at http:// plantpath.ifas.ufl.edu/rsol/NRI_Project/Projectsummary.html (Accessed 25 June 2010).

Churchman, C.W., 1971. The Design of Inquiring Systems Basic Concepts of Systems and Organization. Basic Books, New York.

Cieslik, K. J., Leeuwis, C., Dewulf, A. R. P. J., Lie, R., Werners, S. E., Van Wessel, M., P. Feindt, and Struik, P. C. 2018. Addressing socio-ecological development challenges in the digital age: Exploring the potential of Environmental Virtual Observatories for Connective Action (EVOCA). *NJAS-Wageningen Journal of Life Sciences*, *86*, 2-11.

Coffey, M., Gees, R., 1991. The cytology of development. Adv. Plant Pathol. 7, 31–51. Cohen, Y., Coffey, M.D., 1986. Systemic fungicides and the control of oomycetes. Annu. Rev. Phytopathol. 24, 311–338.

Cooke, L., Schepers, H., Hermansen, A., Bain, R., Bradshaw, N., Ritchie, F., Shaw, D., Evenhuis, A., Kessel, G., Wander, J., 2011. Epidemiology and integrated control of potato late blight in Europe. Potato Res. 54, 183–222.

Damtew, E., Tafesse, S., Lie, R., Van Mierlo, B., Lemega, B., Sharma, K., Leeuwis, C., Struik, P., 2018. Diagnosis of Management of Bacterial Wilt and Late Blight in Potato in Ethiopia: A Systems Thinking Perspective., NJAS –Wageningen Journal of Life Sciences (This Volume).

Davenport, T.H., Prusak, L., 1998. Working Knowledge: How Organizations Manage What They Know. Harvard Business Press.

Denny, T., Brumbley, S., Carney, B., Clough, S., Schell, M., 1994. Phenotype Conversion of Pseudomonas Solanacearum: Its Molecular Basis and Potential Function.

Devaux, A., Kromann, P., Ortiz, O., 2014. Potatoes for sustainable global food security. Potato Res. 57, 185–199.

ESA, 2015. Quality Declared Seed (QDS) –Vegetatively Propagated Potato Seed – Specification, first edition. (Addis Ababa, Ethiopia).

Elphinstone, J., Aley, P., 1993. Integrated control of bacterial wilt of potato in the warm tropics of Peru. Conference paper], ACIAR Proceedings-Australian Centre for International Agricultural Research (Australia). No. 45.

Elphinstone, J., Allen, C., Prior, P., Hayward, A., 2005. The Current Bacterial Wilt Situation: a Global Overview, Bacterial Wilt Disease and the Ralstonia Solanacearum Species Complex. pp. 9–28.

Elphinstone, J., 2005. The current bacterial wilt situation: a global overview. Pages 9–28. In: Allen, C., Prior, P., Hayward, A.C. (Eds.), Bacterial Wilt: The Disease and the Ralstonia Solanacearum Species Complex. American Phytopathological Society, St. Paul, MN.

Erwin, D.C., Ribeiro, O.K., 1996. Phytophthora Diseases Worldwide. American Phytopathological Society (APS Press).

FAO, 2008. Potato World Africa-International Year of the Potato 2008: New Light on a Hidden Treasure. Food and Agriculture Organization of the United Nations, Rome.

French, E., 1994. Integrated Control of Bacterial Wilt of Potatoes, CIP Circular (CIP).

Garrett, K., Nelson, R., Mundt, C., Chacon, G., Jaramillo, R., Forbes, G., 2001. The effects of host diversity and other management components on epidemics of potato late blight in the humid highland tropics. Phytopathology 91, 993–1000.

Genin, S., 2010. Molecular traits controlling host range and adaptation to plants in Ralstonia solanacearum. New Phytol. 187, 920–928.

Gildemacher, P.R., Kaguongo, W., Ortiz, O., Tesfaye, A., Woldegiorgis, G., Wagoire, W.W., Kakuhenzire, R., Kinyae, P.M., Nyongesa, M., Struik, P.C., Leeuwis, C., 2009a. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Res. 52, 173–205.

Gildemacher, P.R., Demo, Paul, Barker, Ian, Kaguongo, Wachira, Woldegiorgis, Gebremedhin, Wagoire, William W., Wakahiu, Mercy, Leeuwis, Cees, Struik, Paul C., 2009b. A description of seed potato systems in Kenya, Uganda and Ethiopia. Am. J. Potato Res. 86, 373–382.

Gorfu, G., Woldegiorgis, B., 2013. Bacterial wilt: an emerging threat to Ethiopian potato industry. Pages 211–222 in: seed potato tuber production and dissemination: experiences, challenges and prospects. In: Woldegiorgis, G., Berihun, B., Schultz, S. (Eds.), Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination. 12-14 March 2012, Bahir Dar, Ethiopia.

Harrison, J., 1995. Factors Involved in the Development of Potato Late Blight Disease (Phytophthora Infestans), Potato Modeling and Ecology of Crops Under Conditions Limiting Growth. Kluwer, London, pp. 215–236.

Haverkort, A., Koesveld, M., van Schepers, H., Wijnands, J., Wustman, R., Zhang, X., 2012. Potato Prospects for Ethiopia: on the Road to Value Addition 66 PPO-AGV, Lelystad.

Hayward, A., 1991. Biology and epidemiology of bacterial wilt caused by Pseudomonas solanacearum. Annu. Rev. Phytopathol. 29, 65–87.

Henok, K., Fassil, A., Yaynu, H., 2007. Evaluation of Ethiopian isolates of Pseudomonas fluorescens as biological agent against potato bacterial wilt caused by Ralstonia (Pseudomonas) solanacearum. Acta Agriculturae Slovenica 90, 125–135.

Hirpa, A., Meuwissen, M.P., Tesfaye, A., Lommen, W.J., Lansink, A.O., Tsegaye, A., Struik, P.C., 2010. Analysis of seed potato systems in Ethiopia. Am. J. Potato Res. 87, 537–552.

Huet, G., 2014. Breeding for resistances to Ralstonia solanacearum. Front. Plant Sci. 5. Ingram, D.S., Williams, P.H., 1991. Phytophthora Infestans, the Cause of Late Blight of Potato.

Janse, J., 1996. Potato brown rot in Western Europe–history, present occurrence and some remarks on possible origin, epidemiology and control strategies. EPPO Bull. 26, 679–695.

Kassa, B., Eshetu, B., 2008. Potato disease management. Pages 79–96. In: Woldegiorgis, G., Gebre, E., Lemaga, B. (Eds.), Root and Tuber Crops: The Untapped Resources. Ethiopian Institute of Agricultural Research, Addis Ababa.

Ke-qiang, C., Forrer, H., 2001. Current status and prosperity on biological control of potato late blight (Phytophthora infestans). J. Agric. Univ. Hebei 24, 51–58.

Kirk, W., Abu-El Samen, F., Muhinyuza, J., Hammerschmidt, R., Douches, D., Thill, C., Groza, H., Thompson, A., 2005. Evaluation of potato late blight management utilizing host plant resistance and reduced rates and frequencies of fungicide applications. Crop Prot. 24, 961–970.

Lal, M., Yadav, S., Sharma, S., Singh, B., Kaushik, S., 2017. Integrated management of late blight of potato. J. Appl. Nat. Sci. 9, 1821–1824.

Leeuwis, C., 2004. Communication for Rural Innovation. Rethinking Agricultural Extension, 3rd ed. Blackwell Science, Oxford.

Lemaga, B., Kanzikwera, R., Kakuhenzire, R., Hakiza, J., Manzi, G., 2001a. The effect of crop rotation on bacterial wilt incidence and potato tuber yield. Afr. Crop Sci. J. 9, 257–266.

Lemaga, B., Siriri, D., Ebanyat, P., 2001b. Effect of soil amendments on bacterial wilt incidence and yield of potatoes in southwestern Uganda. Afr. Crop Sci. J. 9, 267–278.

Lemaga, B., Kakuhenzire, R., Kassa, B., Ewell, P., Priou, S., Allen, C., Prior, P., Hayward, A., 2005. Integrated Control of Potato Bacterial Wilt in Eastern Africa: the Experience of African Highlands Initiative, Bacterial Wilt Disease and the Ralstonia Solanacearum Species Complex. pp. 145–157.

Lemessa, F., Zeller, W., 2007. Isolation and characterisation of Ralstonia solanacearum strains from Solanaceae crops in Ethiopia. J. Basic Microbiol. 47, 40–49.

Li, J.-G., Dong, Y.-H., 2013. Effect of a rock dust amendment on disease severity of tomato bacterial wilt. Antonie Van Leeuwenhoek 103, 11–22.

Lima, M., Maffia, L., Barreto, R., Mizubuti, E., 2009. Phytophthora infestans in a subtropical region: survival on tomato debris, temporal dynamics of airborne sporangia and alternative hosts. Plant Pathol. 58, 87–99.

Lundvall, B.-Å., Johnson, B., 1994. The learning economy. J. Ind. Stud. 1, 23–42. Lundvall, B.-A., 1992. National Innovation System: Towards a Theory of Innovation and Interactive Learning. Pinter, London.

Meijerink, G., Bulte, E., Alemu, D., 2014. Formal institutions and social capital in value chains: the case of the Ethiopian Commodity Exchange. Food Policy 49, 1–12.

Mizubuti, E.S., Fry, W.E., 1998. Temperature effects on developmental stages of isolates from three clonal lineages of Phytophthora infestans. Phytopathology 88, 837–843.

Mizubuti, E.S., Aylor, D.E., Fry, W.E., 2000. Survival of Phytophthora infestans sporangia exposed to solar radiation. Phytopathology 90, 78–84.

Namanda, S., Olanya, O., Adipala, E., Hakiza, J., El-Bedewy, R., Baghsari, A., Ewell, P., 2004. Fungicide application and host-resistance for potato late blight management: benefits assessment from on-farm studies in SW Uganda. Crop Prot. 23, 1075–1083.

Nonaka, I., 1991. The knowledge-creating company. Harv. Bus. Rev. (November–December 1991) 71 (6), 96–104. Nyankanga, R., Wien, H., Olanya, O., Ojiambo, P., 2004. Farmers' cultural practices and management of potato late blight in Kenya highlands: implications for development of integrated disease management. Int. J. Pest Manage. 50, 135–144.

Ortiz, O., Kroschel, J., Alcázar, J., Orrego, R., Pradel, W., 2009. Evaluating Dissemination and Impact of IPM: Lessons from Case Studies of Potato and Sweetpotato IPM in Peru and Other Latin American Countries, Integrated Pest Management: Dissemination and Impact. Springer, pp. 419–434.

Ostrom, E., 1990. Governing the Commons: the Evolution of Institutions for Collective Action. Cambridge University Press, NewYork.

Polanyi, M., 1967. The Tacit Dimension. Routledge and Kegan Paul, London. Pradhanang, P., Pandey, R., Ghimire, S., Dhital, B., Subedi, A., 1993. An approach to management of bacterial wilt of potato through crop rotation and farmers' participation. In: ACiAR Proceedings. Australian Centre for International Agricultural Research. 362–362.

Priou, S., Aley, P., Chujoy, E., Lemaga, B., French, E., French, E., 1999. Integrated Control of Bacterial Wilt of Potato, CIP Slide Training Series IV-3. International Potato, Citeseer.

Priou, S., Salas, C., De Mendiburu, F., Aley, P., Gutarra, L., 2001. Assessment of latent infection frequency in progeny tubers of advanced potatoclones resistant to bacterial wilt: a new selection criterion. Potato Res. 44, 359–373.

Scholthof, K.-B.G., 2007. The disease triangle: pathogens, the environment and society, Nature Reviews. Microbiology 5, 152.

Schulz, G., Woldegiorgis, G., Hailemariam, A., Aliyi, J., Haar, W., 2013. Sustainable seed potato production in Ethiopia: from farm-saved to quality declared seed. Pages 61–71 in: seed potato tuber production and dissemination: experiences, challenges and prospects. In: Woldegiorgis, G., Berihun, B., Schultz, S. (Eds.), Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination. 12–14 March 2012, Bahir Dar, Ethiopia.

Schumann, G.L., D'Arcy, C.J., 2006. Essential Plant Pathology. American Phytopathological Society (APS Press).

Schumann, G.L., 1991. Plant Diseases: Their Biology and Social Impact. APS Press. Shimelash, D., 2015. Diversity of Phytophthora Infestans (Mont.) De Bary on Potato (Solanum Tuberosum L.) and Tomato (Solanum Lycopersicum Mill.) in Ethiopia.

Shove, E., Pantzar, M., Wason, M., 2012. The Dynamics of Social Practice: Everyday Life and How It Changes. Sage.

Shtienberg, D., 2013. Will decision-support systems be widely used for the management of plant diseases? Annu. Rev. Phytopathol. 51, 1–16.

Struik, P., Askew, M., Sonnino, A., Mackerron, D., Bång, U., Ritter, E., Statham, O., Kirkman, M., Umaerus, V., 1997. Forty years of potato research: highlights, achievements and prospects. Potato Res. 40, 5–18.

Swanson, J.K., Montes, L., Mejia, L., Allen, C., 2007. Detection of latent infections of Ralstonia solanacearum race 3 biovar 2 in geranium. Plant Dis. 91, 828–834.

Tesfaye, A., Woldegiorgis, G., Kaguongo, W., Lemaga, B., 2013. Adoption and impact of potato production technologies in Oromia and Amhara regions. Pages 256–278 in: seed potato tuber production and dissemination: experiences, challenges and prospects. In: Woldegiorgis, G., Berihun, B., Schultz, S. (Eds.), Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination. 12–14 March 2012, Bahir Dar, Ethiopia.

Van de Fliert, E., Braun, A., Ghimire, S.R., Brons, J., 1998. Three Cases and a Model: Application of an Integrative, Participatory R&D Framework to UPWARD Projects in Indonesia, Nepal and the Philippines, UPWARD, Sustainable Livelihood for Rural Households: Contribution from Rootcrop Agriculture. pp. 99–109.

Van der Plank, J.E., 2013. Plant Diseases: Epidemics and Control. Elsevier.

Van der plank, J.E., 2012. Host-Pathogen Interactions in Plant Disease. Elsevier.

Vasse, J., Danoun, S., Trigalet, A., Allen, C., Prior, P., Hayward, A., 2005. Microscopic Studies of Root Infection in Resistant Tomato Cultivar Hawaii7996, Bacterial Wilt Disease and the Ralstonia Solanacearum Species Complex. pp. 285–291.

Wharton, P., Kirk, W., Baker, K., Duynslager, L., 2008. A web-based interactive system for risk management of potato late blight in Michigan. Comput. Electron. Agric. 61, 136–148.

Whipps, J., Gerhardson, B., 2007. Biological Pesticides for Control of Seed-And Soil-Borne Plant Pathogens, Modern Soil Microbiology, 2nd edn. CRC Press, Boca Raton, USA, pp. 479–502.

Woldegiorgis, G., Gebre, E., Lemaga, B., 2008. Overview of trends in root and tuber crops research in Ethiopia. In: Woldegiorgis, G., Gebre, E., Lemaga, B. (Eds.), Pages 1–5 in Root and Tuber Crops: The Untapped Resources. Ethiopian Institute of Agricultural Research (EIAR) ISBN: 978–99944-53–19-1.

Yabuuchi, E., Kosako, Yoshimasa, Yano, Ikuya, Hotta, Hisako, Nishiuchi, Yukiko, 1995. Transfer of two Burkholderia and an Alcaligenes species to Ralstonia gen. nov: proposal of Ralstonia pickettii (Ralston, Palleroni and Doudoroff 1973) comb. nov., Ralstonia solanacearum (Smith 1896) comb. nov. and Ralstonia eutropha (Davis 1969) comb. nov. Microbiol. Immunol. 39, 897–904.

Yuliar, Nion, Y.A., Toyota, K., 2015. Recent trends in control methods for bacterial wilt diseases caused by Ralstonia solanacearum. Microbes Environ. 30, 1–11.

4

Chapter 4

Governing a collective bad: social learning in the management of crop diseases[14]

published as: [14] Damtew, E., van Mierlo, B., Lie, R., Struik, P., Leeuwis, C., Lemaga, B. and Smart, C.
Governing a Collective Bad: Social Learning in the Management of Crop Diseases.
Systemic Practice and Action Research, 33(1), pp.111-134.

Abstract

There has been strong research interest in designing and testing learning approaches for enhancing and sustaining the capacity of communities to manage collective action problems. Broadening the perspective from well-known social learning approaches in natural resource management, this study explores how social learning as a communicative process influences collective action in contagious crop disease management. A series of facilitated discussion and reflection sessions about late blight management created the social learning space for potato farmers in Ethiopia. Communicative utterances of participants in the sessions served as the units of analysis. The study demonstrates how and to what extent social learning, in the form of aligned new knowledge, relations and actions occurred and formed the basis for collective action in the management of late blight.

Keywords:
Crop disease; Late blight; Social learning; Collective action; Communication

Introduction

Potato late blight disease represents a serious problem for farmers in almost all major potato-growing areas (Tsedaley, 2014; Mekonen et al., 2011; Kassa and Beyene, 2001). On-station studies estimate yield loss[1] in Ethiopia to range from 6% to 100% depending on the level of susceptibility of the variety (Guchi, 2015; Mesfin and Woldegiorgis, 2007). As late blight is air-borne and the causal agent (*Phytophthora infestans*) travels across farm boundaries, it is not just a problem of an individual farmer but a collective problem of all farmers in a geographical area (Miller et al., 2006). The propensity of late blight pathogen to traverse farm boundaries means that control efforts by any farmer confer a benefit to other nearby farmers. It also means that lack of control on any property stimulates the development of the epidemic and thus imposes costs or losses on other properties (Graham et al., 2018; Marshall et al., 2016). Miranowski and Carlson (1986), in their seminal work, stress the critical role of the mobility of diseases and pests in designing collective management responses. Accordingly, the search for solutions and management practices should take into consideration, on one hand, technical effectiveness and, on the other hand, institutional mechanisms that stimulate and facilitate collective management at the appropriate scale (Graham et al., 2018; Zamani et al., 2018; Marshall, 2011). To this end, there is a well-established research effort in designing and testing approaches aimed at enhancing collective capacity in the management of agricultural pests and diseases, generally engaging farming communities in a variety of communal management practices (Hegde, 2017; Christmann et al., 2015; Biedenweg and Monroe, 2013a).

In the broader field of socio-ecological systems, stimulating social learning is a common recommendation for developing and sustaining the capacity of managing collective action problems(Mostert et al. 2007; Pahl-Wostl and Hare 2004; Rist et al. 2003; Schusler et al. 2003; Leeuwis and Pyburn 2002; Wollenberg et al. 2001). In this body of literature, social learning is extensively examined as a conceptual and methodological approach in facilitating knowledge generation and in forging new types of social relationships among resource users that have to deal with collective action problems. Conceptual perspectives on social learning predominantly take learning as an outcome or end result. Consequently, there is limited insight into salient processes and interactions that trigger a change in individual or collective decisions and actions in the management of socio-ecological problems (Amanda et al. 2018; Beers et al. 2016; Pahl-Wostl 2007). Furthermore, there is a tendency to limit social learning outcomes to consensus or agreements (as 'identification of adaptation options', 'agreement on a common purpose' or 'design of governance processes and arrangements') providing little information on whether such agreements instigated action in actual practice. (e.g. Graham et al. 2018; Hegde et al. 2017; Christmann et al. 2015; Scholtz et al. 2014).

1 We were not able to find studies that tried to quantify yield loss at farm level

Another significant feature of this type of research is the implicit assumption that some sort of recognition of the ecological or biophysical aspect of a collective problem exists among appropriators or public good providers (Bell et al., 2016; Cárdenas et al., 2015; Brugnach et al., 2011). With this background, the focus of research is often directed towards understanding 'how' or 'in what circumstances' social learning facilitates knowledge generation and sharing among common pool resource users as well as the social relations necessary for effective collective action on an already recognized collective problem. Such framing poses a particular challenge for the management of contagious crop diseases like late blight. The collective nature of the problem can be unclear to farmers due to the poor visibility of the life cycle and mobility of the pathogen, particularly when compared to other common-pool resources (e.g. forest, fish, irrigation management) or 'public bads' (e.g. invasive weeds, migratory pests). As a consequence, previous research in the study area indicated most farmers do not recognize late blight as a collective problem, mainly seeing it as a private bad (Shiferaw et al., 2018). Against this background, we consider that social learning approaches for disease management need to pay sufficient attention to learning about key technical aspects of diseases that are characterized by less visible dynamics in the eyes of farmers (e.g. involving oomycete, viruses, bacteria, fungi) and this could play a crucial role in redefining the nature of the problem.

By taking a process-oriented perspective to learning, this study aims to understand how collective action in late blight management develops in a social learning process. It shows how social learning emerges in an organized learning space for potato farmers in Ethiopia and how it effects collective action of these farmers. In this way, it intends to offer fresh theoretical and practical perspectives on contagious diseases such as potato late blight as a collective bad and, correspondingly, the role of social learning in crop disease management.

The paper is organized as follows. Section 4.2 presents a detailed synthesis of our conceptual framework on collective action and social learning setting the scene for our research questions in the same section. Section 4.3 provides details of the research methodology where the case study context is also described. Our research findings are presented in section 4.4 and then discussed in section 4.5, followed by conclusions in section 4.6.

Conceptual framework

Collective action in natural resource management

Drawing upon Olsen's (1965) notion of a collective good, Marshall (1998) defines collective action as an action taken by a group, either directly or on its behalf by an organization, in pursuit of members' perceived shared interests. Whether a particular collective action concerns a public good or a public bad is an empirical, subjective issue because resource users may either suffer from a bad or fail to benefit from a good (Hardin, 2015). This perspective entails that while contagious diseases like late blight are generally presented as a public bad that needs to be prevented, collective action provisions towards their management can also be regarded as a public good. In either perception, recognition of the collective nature of the disease is important, as was stated in the introduction.

In public good governance in the realm of agriculture and natural resource management, two types of collective action are distinguished: (1) *cooperation*: bottom-up, farmer-to-farmer collective action; and (2) *coordination* that is characterized by a top-down, agency-led collective action approach (Poteete et al., 2009; Davies et al., 2004). Broader debates around the development and success of collective action focus on key performance factors and barriers to be addressed to produce benefits from collective action. Hence, successful initiatives must overcome the most common barriers to collective action (Uetake, 2012; Davies et al., 2004). In this regard, a range of substantive factors can govern the performance of collective action initiatives (Poteete and Janssen, 2009; Heffernan et al., 2008). Collective action is, first, highly affected by the characteristics of the natural resource (type of good) involved and on the knowledge and the predictability of the resource. The successful integration of knowledge is key to enable communities to govern their public good/bad in a sustainable way (Pahl-Wostl et al., 2009; Pretty 2003). Second, the social dynamics of the group involved, their shared interests and voluntary actions to pursue those shared interests are also significant. In these dynamics, community members should also improve their social relationships to overcome their collective problems (Meinzen-Dick et al., 2004). As Ostrom (1990) highlighted, collective action is also determined by institutional arrangements, involving both locally devised, simple rules and effective monitoring and sanction systems.

In the light of the above, it can be argued that the achievement of collective action in the management of crop diseases like late blight involves significant changes in two dimensions: a change in technical knowledge about the nature of the disease and a shift in social and institutional arrangements (Deuffic and Candau, 2006). As illustrated in the next sub-section, the important challenges or success factors discussed here strongly relate to the central role of social learning in the transformation of knowledge, norms and rules amongst resource users in collective action initiatives (Leeuwis and Pyburn, 2002; Röling and Wagemakers, 2000).

Social learning: technical and relational dimensions

Social learning is a broad concept and is operationalized differently in different disciplines and contexts (Koontz, 2014). In the domain of natural resource management, social learning is essentially appreciated as occurring when people are brought together to share perspectives and experiences to develop a common framework of understanding as a basis for joint action (Reed et al., 2010; Pahl-Wostl et al., 2009; Schusler et al., 2003).

The literature broadly distinguishes between technical[2] and relational dimensions of social learning (Phuong, 2017; Koontz, 2014; Scholz et al., 2014; Woodhill, 2010; Pahl-Wostl et al., 2007; Bouwen and Taillieu, 2004; Campilan, 2002). The technical dimension concerns new knowledge or insights that relate to the natural or biophysical aspect of the problem situation. The relational aspect refers to emergent social properties, such as establishing new relations, breaking existing relations, and building trust and commitment to a group vision as groups become aware of their mutual interdependencies (Beers, 2016; Koontz, 2014; Reed et al., 2010). In this regard, the technical learning dimension relates to addressing the first determining factor for the success of collective action, namely knowledge about the nature of natural resource at hand. The relational aspect of social learning conforms directly with social competencies needed to deal with the second collective action performance-influencing factor. Social learning is also about creating opportunities for institutional change, relevant in the governance of collective action problems. (Gerritsen et al., 2013; Scholz et al., 2013). Correspondingly, we argue that apart from normative institutions (e.g. issues of trust, reciprocity), regulative institutions as in the form of defining or redefining of rules of engagement for collective action fall within the relational sphere of social learning.

Social learning as a communicative process with outcomes

A salient notion in the conceptualization and operationalization of social learning relates to seeing learning as a process and/or an outcome. As stated before, in the natural resource management domain, social learning is often defined in relation to a wide range of potential outcomes it may have (Biedenweg and Monroe, 2013a; Scholz et al., 2014; Paul-Wostl et al., 2007). The essence of considering social learning as a process with outcomes has been highlighted in literature informed by learning theories from other fields like educational science and organizational learning (Beers et al. 2016; Biedenweg and Monroe, 2013b; Senge, 2006). Different learning processes can relate to different learning outcomes and an outcome is preceded by various framings, communicative interactions or coalition building processes (Van Der Stoep et al., 2016; Pahl-Wostl, 2002*;* Joss and Brownlea, 1999). Hence, one way of making claims about tangible outcomes of social learning is tracking communications and explaining the context in which it was observed (Rodela, 2013). By examining communication among participants, it is possible to unravel how learning processes lead to tangible outcomes (Beers et al., 2016; Rist et al., 2006; Pahl-Wostl and Hare, 2004; Lamerichs and Molder, 2002). This constructivist approach regards communication not merely as a process of getting a message across, but as a phenomenon in which those involved construct meanings in interaction (Leeuwis and Aarts, 2011; Aarts

2 For what we call the technical aspect, different terms are used by social learning scholars such as content aspect, task-oriented dimension, biophysical aspect, ecological processes, environmental functions, natural environment, etc.

and van Woerkum, 2008; Te Molder and Potter, 2005). Communication itself is regarded as an (inter)action that has direct consequences for the social and material world (e.g. relations may be damaged, parties no longer meet, violence may emerge, etc.). From a communication perspective, collective action is, therefore, dependent on a change in communication, representations, and storylines that are mobilized by interaction (Bentley et al., 2018; Leeuwis and Aarts, 2011).

Assuming that social learning takes place in communicative activities, means that it must become visible in, and can be identified in communication. As Beers et al., (2016) highlighted the knowledge, relational and (collective) action dimensions are aspects of the content of the communication (i.e., what people talk about) and the social learning process is a communicative activity that aligns these three dimensions.

There is a distinction between (collective) action in communication, in the form of agreements, proposals or decisions and physical (collective) action (actual implementation of agreements on the ground) (Beers et al., 2016). While collective action in the form of agreements is treated in our study within the communicative aspect of social learning, the actual implementation (physical action) of the communicated agreement is regarded as an external outcome or impact of social learning. In view of our conceptual disposition, social learning is, therefore, a communicative process in which new or changed technical knowledge, social relations and suggested actions become aligned and may turn into collective agreements. As depicted in Figure 1, these learning outcomes may further effect collective action in the management of late blight.

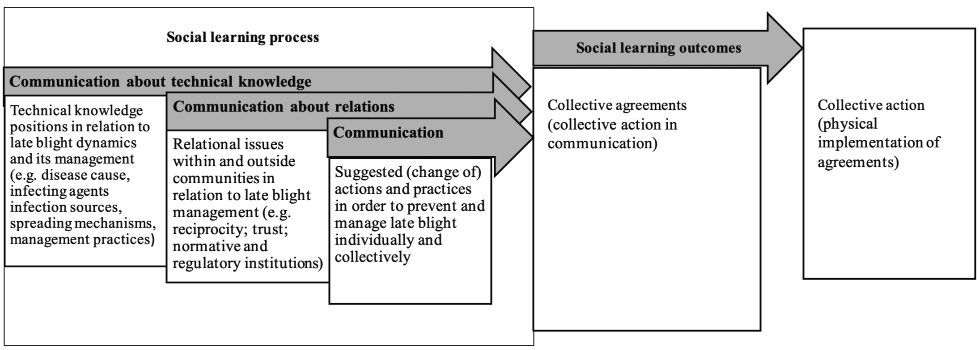


Figure 1:

Conceptual framework with perspectives from Beers et al. (2016), Bentley et al. (2018), Ostrom (1990); Scholz et al. (2013) and Rodela (2013).

Informed by the literature gaps highlighted in the introduction and our conceptual framing as well as the case study to which it is geared, this study addresses the following research questions:

Main research question: How does social learning as a communicative process influence collective action in late blight management by farmers? This main research question is sub-divided into:

1. How do aligned technical knowledge, relations and suggested actions emerge in communicative utterances and relate with collective agreements?

2. To what extent and how do collective agreements translate into collective actions in the management of late blight?

Methodology

Case study context

The case study was conducted in a village (Goro) found in Wolmera district of Ethiopia's Oromia regional state. The village was selected considering issues such as production potential (it is designated as 'potato cluster' by the district), accessibility and the existence of suitable adjacent potato plots to justify collective risk situation. A total of 33 potato farmers participated in the case study. The livelihood of most farmers in the study area is primarily dependent on the cultivation of potato but also on other cereals and pulses such as wheat, barley, beans and chickpea. Most of the participant farmers are ware potato producers whereby they use a small portion of their produce for household food consumption and sell the rest in local markets as food potato. There was a seed potato producing cooperative in the area that only a few of the farmers used to participate in. The district office of agriculture was in charge of organizing the cooperatives and facilitating access to input supply and market outlets to other potato producing areas in the country. As it is further illustrated in the result section, there had been some trust issues between the farmers and the district office of agriculture, and among the farmers themselves that had consequences to the social learning process and outcomes.

Setting up a social learning context

From a methodological perspective, social learning takes place in an ongoing chain of interactions, such as face-to-face meetings. These interactions offer a communication space for knowledge generation and sharing, social action and reflection (Beers et al., 2016; Leeuwis and Aarts, 2011). The communicative interaction can be a spontaneous, self-organized natural process or something induced and guided by an external facilitator (Koontz, 2014). Well-known strategies to facilitate interactions include the organization of discussion and reflection meetings. In addition, practical actions and experiments to visualize unknown biophysical processes with the help of discovery learning tools can be relevant communicative strategies for supporting social learning if they elicit communication (Leeuwis and Aarts, 2011; Loorbach, 2007; Leeuwis et al., 2002).

A potato scientist, with support from the community extension worker, facilitated the technical learning sessions and the first author of this paper facilitated the reflexive, follow-up meetings. Following Ford's (1999) suggestion, the design of the learning context was arranged in such a way that it provided generic themes that guided the unfolding conversations around different technical or social issues in relation to late blight management. In this regard, the social learning context was configured through concurrent technical (conceptual and practical) sessions and reflexive meetings that were meant to inspire discussions, learning and collective action in the management of the disease. There was a total of ten such learning sessions that contained technical sessions with reflexive follow-up meetings. Each learning session took an average of two and half hours. The first two sessions were focused on disease dynamics (definition, cause, symptoms and spreading mechanisms) and opportunities for disease surveillance. The remaining eight sessions, spread across the four-month growing season of the potato crop (June-September), were designed to facilitate social learning as participants were able to exchange perspectives, negotiate, discuss success and pitfalls, and agree or disagree around different technical and relational issues in the management of the disease. As listed below, most of the learning sessions had three major parts; the first part was covered mainly in the technical sessions and the other two during reflective meetings. However, as different discussion topics were interrelated, there were apparent overlaps of the discussion agendas across the learning sessions.

- Facilitated discussion and field practical observation on the disease and its management
- Report and reflection session on activities since the previous learning session
- Deliberation on activities before the next learning session

The technical sessions provided a learning space on less visible biophysical aspects of late blight, such as signs and symptoms, causal agent and spreading mechanisms. A magnifying glass, YouTube videos and potato sizing squares were used to showcase and initiate discussion around late blight spreading mechanisms, symptoms and seed selection as management practices. Practical sessions on some relevant late blight management options took place through observation and discussion on plant growth, weather conditions and on how to implement different management options. The practical sessions were partly informed by CIP (International Potato Center) previous learning material (Cáceres et al., 2008). For the technical learning sessions, a small community-managed plot ($30m^2$ x$30m^2$) was secured from a farmer and was planted with a third-generation potato seed provided by Holeta Agricultural Research Center.

Data collection

Utterances from the ten learning and reflexive meeting sessions were fully captured to particularly answer our first research question on how social learning outcomes as an alignment of changed knowledge, relations and actions were developed in participants' communicative utterances. Continuous documentation and audio recording were made on each learning session in which different learning themes about the disease and its management were covered. During these facilitated sessions, particular attention was given to participants' reflections on new insights related to the disease; the way they made sense of their existing knowledge or practice in view of new information; and how and what social or technical practices they thought had to be unchanged or modified in the management of late blight. Plenary field discussions during the technical learning sessions and follow-up, reflexive meetings (which together constituted one learning session) were important deliberative spaces for generating this information. Data for our second research question that assessed the extent to which social learning outcomes were translated into collective actions on the ground was obtained from a monitoring sheet that was filled in and presented by a monitoring committee during the reflexive, follow-up meetings with all participants. The monitoring sheet captured information on *farmer name; type of collective practice; date of monitoring; way of communication; adherence/non-adherence; measures taken*. The researchers' field observation and participation in some of the monitoring work were additional sources of information.

Data analysis

The study report is based on analysis of extensive meeting notes or verbatim meeting transcripts. Thus, our units of analysis are transcribed utterances of participants during the learning and reflexive meetings. Each social learning event was regarded as a particular communicative space containing various utterances of participants and hence fully transcribed verbatim. As different learning themes around the nature of the disease and the management options did not necessarily begin and end with the learning sessions and usually went beyond more than one session, all discussions from the different learning sessions that related to a particular theme (e.g. fungicide spray) were openly coded on Atlas.ti software. Accordingly, we defined five themes in the communication: *nature of the disease, fungicide use, late blight resistant and clean seed potato, killing/rouging volunteers* and *dehaulming*.

The second stage, axial coding followed, drawing on our conceptual line of thinking on social learning as an alignment of new or changed knowledge, relationships and actions. In doing this, all quotes under the five codes were analyzed for text segments in which new or changed technical knowledge, relation and suggested management actions and practices were aligned. In nine data segments, the three dimensions had become aligned, leading to a collective agreement. These segments were taken as evidence of a process of social learning and are discussed as emergent sub-topics under the different codes. Collective agreements that followed upon such moments of alignment were regarded as the first outcomes of social learning. Finally, the analysis of the translation of collective agreements into physical collective action was based on the information from a monitoring report by the farmers' committee and the notes from follow-up discussions in the reflexive meetings.

Results

The results section consists of three major parts. The first two sections (4.4.1 and 4.4.2) present how the social learning process as a communicative interaction led to social learning outcomes across the different discussion topics entertained in the learning and reflective sessions. The third section (4.4.3) presents a summary of the level of translation of the social learning outcomes into collective action.

Learning about the nature of the disease

Discussions about the disease in relation to its cause, symptoms and spreading mechanisms sparked different kinds of relational and action-oriented discussions. As can be seen from Figure 2, utterances about the disease shifted from regarding late blight as a weather problem to regarding it as a disease with multiple infection sources. During this initial stage of the learning sessions and particularly in the first two sessions, new insights about the cause[3] and spreading mechanism brought the issue of interdependency among neighboring farmers to the center of conversations. The realization of late blight as a communal problem provided many of the participants a new lens on the way they see farmer-to-farm relationships in the management of late blight. There were marked comments on how farmers could be affected by the situation on neighboring farms and what can be done about the disease. As many stressed the importance of cooperation in managing the disease, a proposal was made by a few farmers, and endorsed by all of the other farmers present, to involve other farmers in the community that were not in the meetings. Table 1 shows how this collective agreement was related to alignment of the three dimensions of the topic in the learning process. The proposition from this group of farmers was based on articulations of their understanding of the contagious nature of the disease and their apparent practical observations of how their field had been infected directly after they had observed symptoms on adjacent fields.

3 The causal agent (*Phythophthora Infestans*) is an oomycete but that in practice it is usually called a fungus and therefore the chemical controlling it is not called an oomycide but a fungicide.

Table 1: Learning to bring on board other farmers in the community.

Technical	"This is new information to me. I never thought that late blight can spread from field to field. I never cared unless I see it on my own field."
Relational	"Just like communal livestock grazing fields and water channels management, we also affect each other with late blight." "Listen please; the disease can spread from his farm to my farm. What are we going to do about the other farmers who are not here?" "I have a neighbor, she barely looks after her field. She has never come to our meeting. We are sharing a boundary and she should be part of our concern."
Action	"Whether they belong here or not, they need to be told." "We will not persuade other farmers who are not here, but we should advise them with love to join our group."

An interesting proposal that followed discussions on late blight transmission and the communal risk of the disease was the importance of monitoring late blight incidence beyond their individual farms. Even though all farmers inspected their own fields to a different degree, an agreement that a group of neighboring farmers should team-up for an early morning joint field scout was accompanied by statements about the communal risk nature of the disease and the need for adjusting existing individual-based practice in monitoring. The joint field scout was an idea that was particularly pushed by a few former seed-producing farmers who had experience of crop disease monitoring.

Conversely, some farmers argued they could control the disease on their field, irrespective of what is happening on neighboring farms. As can be observed in some of the statements below, their choice to continue working individually was mainly heralded by utterances of their previous experience of keeping the problem at bay by optimal spraying, despite their belief that late blight is a contagious disease: *"I am always well prepared with chemicals; my field is usually safe when neighboring fields are hit with* Wag *[late blight]"...."As Baysa said, if I spray enough I can protect my own field"....."The owner himself can control it daily; it doesn't cause that much problem."* Of these five farmers, all but one eventually decided not to be part of the collective monitoring work and missed the subsequent learning and reflexive sessions.

Different statements disclosed that the farmers, in general, had experience with some sort of monitoring in their diverse social endeavors, such as community health and security matters. A fascinating relational issue that was raised and discussed before an agreement was reached on joint monitoring was how to deal with the existing traditional view that strangers entering crop fields leads to a drop in productivity. This was particularly raised by some younger farmers as a potential problem for traditional or superstitious members of the community. Although none of the farmers openly said that they did not want other farmers to enter their farm, they all generally acknowledged this as an existing belief that might pose a challenge to joint late blight monitoring. As illustrated in Table 2, the discussion around this issue was concluded with a collective agreement that all farmers should welcome a monitoring committee or a neighboring farmer in the field scout team.

Table 2: Learning about team field scouting and collective monitoring of late blight incidence.

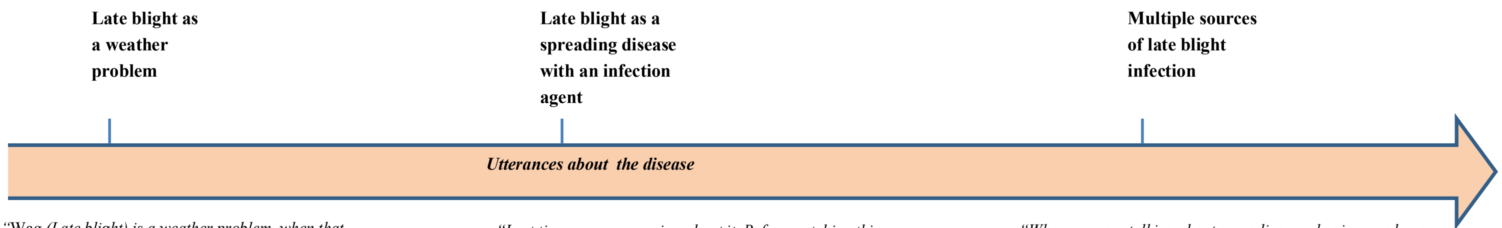
Technical	"The disease can jump from another field to my field that is a problem!" "Some farmers only check their field every three days and some, like Negash, check every morning; this is a problem."
Relational	"We can see each other's field. If Adugna doesn't see his farm, I have to see it as I don't want the disease to be transmitted to my farm." "We can have a group of two or three farmers next to each other to check all the farms together or when others are not available." "We usually have committees; we even used to have a committee for monitoring Gind ateweleg (bacterial wilt) as seed producers." "One thing that we need to talk openly here is that some of us would have an issue of letting other people into our farm." "It is from a cultural view, you will be fearful to visit others farm from the culture" "Yes, we shouldn't cover this up, we may agree here but when we go for implementing that would be a challenge." "It might not be a problem of all farmers but all of us should be willing to check upon one another." "We are working together here, so we should do the late blight detection together and let the monitoring committee into our farm to verify activities."
Action	"As we have a collective job, we should organize a committee. It is a must to organize a committee to perform this work." "I think it is good to elect the committee in a similar way as before, Shambel and Terecha usually represent us." "Tamru also used to work in the seed cooperative committee, he can continue." "We will visit the farm in our area in groups and, if we see the disease, everyone will be alerted"

The idea of what to do with non-compliance was initially brought to the attention of farmers by the facilitator after farmers had decided to introduce team monitoring of late blight incidence. The majority of the farmers were not enthusiastic about sanctions in response to non-compliance, saying everyone should monitor late blight and that sanctions might create friction. Some farmers were less optimistic about compliance and argued that rules were needed: *"we can't be 100% sure that he [a specified farmer] will keep his promises. That is why we need a committee and also the rules."* Another farmer added, "*Any kind of job which will be done in a group must have a ground-rule. If you are a problem for me, we need a common agreement that will prevent you from becoming a problem."* On the contrary, most farmers agreed with the views of two farmers who stressed "*We now know the disease risk, and everyone will do it for their own benefit"* ... "*if there are people who don't participate in the monitoring, it is better to advise them with love than force them."*

As illustrated here, discussions about the disease and its infectious nature led to two social learning outcomes. First, new technical knowledge about the cause and spread of the disease, reflection on their individual monitoring practices and a new way of seeing farmer-to-farm relationships in managing late blight facilitated the agreement to bring other non-participant farmers into their joint work. Second, a shift from seeing late blight as a private problem to a collective problem (new insights on the risk of late blight spread) steered discussion around cooperation and how to deal with an existing belief (bad luck) that led to a proposal for a joint field scout and establishment of a monitoring committee.

Figure 2:

Shifting conversations about the disease.



Late blight as a weather problem

*"*Wag *(Late blight) is a weather problem, when that rosty weather is there it comes and on normal veather."*

'Contrary to what the expert said, we have seen for ong time that a change in weather condition brings ate blight."

'I don't think [late blight] is transmitable. It is just a veather condition: it just comes with alternative change of warm and cold weather, I believe if I spray ny field then I am safe."

'I agree, but I want to know whether [late blight] omes from the warm or cold weather."

"As far as I understand, late blight spreads from plant to plant by the air and kills healthy plants if not treated vith chemical."

'This is new information to me. I never thought that late blight can spread from field to field. I never cared ntil I see it on my own field."

Late blight as a spreading disease with an infection agent

"Last time we were arguing about it. Before watching this video, my assumption was the air itself brings late blight. Now I see it is a disease that can spread. They are living organisms!"

"It is caused by a living thing, so can be transmitted from one farm to the other the same way as Influenza. It is like a virus"

"Late blight is usually seen first in one or two plants in a field and within a day or two, it quickly covers the whole plot, so that is how it transmits to neighbouring farms too."

"Yes, it is caused by a living organism called fungus: we cannot see it with our eyes."

"But someone said it is a virus, is fungus different from a virus?"

"Fungus is a different kind of organism and it is a type fungus that causes late blight."

"Ok so he cannot say virus but what matters is that it is not related with air but it relates with organism."

Multiple sources of late blight infection

"When we were talking about spreading mechanism, we have seen that it uses air to transport itself."

"I am not sure about late blight but I heard that bacterial wilt comes with the seed and from the soil."

"But late blight is a disease in the air so how can you avoid it by changing your potato field?"

"The air only transports the disease. Infected seed or infected plant is the source of the disease. If you have a tuber that is infected and left in the field, we can also say that the field is infected."

"Potato-related plants 'Welfekati' such as tomato and others can also be the source of the disease"

"Gebo [volanteer potato] is another source. After we harvest the main potato and the remaining potato on the field can be a late blight source."

"We had no information that Gebo can be a source of late blight."

"That is true, we all harvest as much as possible and the leftover tubers grow and will be harvested again. We only try to eliminate if we plant a different crop the next season."

Learning about late blight management

In subsequent learning sessions, deliberations on late blight management opened new windows for further reflection on the long-practiced management technique (spraying) and other late blight management options. Analysis of the different statements revealed how communications unfolded to give rise to a range of social learning outcomes.

Fungicide use

Fungicide use for controlling late blight is a well-known practice by all the farmers and its importance was not a point of earnest discussion. Many participants reiterated the view shared by a farmer, namely that: *"chemical has always been our savior."* But as late blight is now recognized as an infectious disease, a new interest surfaced among farmers in knowing if everyone is indeed spraying and if the monitoring committee can check spraying when they receive a report on late blight incidence. The five committee members agreed to share responsibility and individually check spraying on potato fields that are closer to their field. However, during a reflexive meeting after the first monitoring work on spraying, many farmers expressed their dismay that the committee[4] members did not monitor the spraying after they were given reports on late blight incidence from the joint scouting team. This led to a debate on whether the usual representatives are the right people for the work and on the possibility of considering other committed farmers as committee members. This led to an agreement to replace four of the five committee members as shown in Table 3.

Table 3: Learning to replace members of the monitoring committee.

Technical	"The rain has been intense, and we are seeing late blight in different fields." "While we were checking our field yesterday morning, there was late blight on Diro's field. I and Leggesse sprayed in the afternoon before it spreads to our field."
Relational	"The committee did not come and check our field after we reported that there was Wag [late blight]." "That is true, I [a committee member] had been busy at the Kebele." "Two of the committee members are not even here [at this meeting]." "We shouldn't elect/or should not be represented by people who have a lot of responsibility." "This is our work and we should not be afraid of anyone." "Terecha is not active for the work, he is becoming careless. He is my brother but, I am not supporting him."
Action	"So, it is better if we change the members of the committee." "Worku has no workload, he can work for us."

4 The selected committee members were those who had links or worked with external actors such as the local government administration, cooperative unions or rural financial institutions. These members of the community appeared to be perceived as default representatives of the community.

A new notion to most participants was the existence of different types of chemical fungicides with distinct modes of action in late blight control. While some of the farmers shared their knowledge that there are two types of fungicides (Ridomil and Mancozeb), all farmers confirmed that they only used Ridomil (a systemic fungicide) which has market dominance. During discussions, farmers learned that the two fungicides types have different modes of action. Experts considered that continuous use of Ridomil might lead to metalaxyl resistance from the pathogen while farmers questioned whether resistance might be responsible for their increased frequency of Ridomil spray over the years. Most farmers wanted to stop the continuous use of Ridomil and to alternate with Mancozeb which needs application before symptoms are observed. A few farmers, who already bought and saved enough Ridomil for the growing season, rejected the idea of alternating with Mancozeb. After the new committee reported that seven of the 25 farmers who had agreed to spray Mancozeb did not report their spraying schedule for the committee to check, the idea of enforcing rules became again a point of discussion. A consensus was reached (Table 4) that a fine should be proposed at the next meeting when everyone is present to avoid confrontation from absentees. At the next reflexive meeting, an agreement was reached to fine 100 Birr (Ethiopian currency) for those who either missed the joint team scout or failed to inform the committee on the status of late blight and follow-up of the implementation. A further 50 Birr was agreed as the fine for being absent from reflexive meetings

Table 4: Learning about sanctioning systems on non-compliance.

Technical	"One spray of Ridomil used to be effective, now even three times does not work for many of us." "I am not effective with Ridomil anymore, maybe, the disease has already adapted with Ridomil." " Ok, many of us want to try Mancozeb and see the effect in this season."
Relational	"We [committee] were able to check eighteen fields and all sprayed Mancozeb as agreed. Seven people did not call us, so we do not know if they did." "This is a fundamental thing - we need to be careful. Something has to be done to those who are not reporting." "Unless we handle this or bypass without doing anything, the committee can't do anything on their own." "What I think is that instead of punishing a person, it is better to advise them." "For example, when we meet next time if I say; oh, even if I didn't report to the committee, I did spray, what do you do?"
Action	"So, this doesn't need any further discussion, the strict rules must exist and be defined." "Let the committee propose some kind of punishment. They should implement fair punishment based on their observation but not to cause harm to the person." "The rules should be set by all of us and it should be the committee who will take measures." "Today we become strong so that those who didn't report know the consequences."

After the third monitoring on spraying, farmers realized that putting a system of sanctions in place could still not guarantee full compliance. Two farmers who had failed to report on spraying said that they could not spray because they did not have money to buy fungicide. While some farmers tried to protect these two farmers from possible fines, others argued for financial support for these farmers because all farmers are at risk if two farmers are unable to spray. In this regard, the practice of mutual aid that they do in other aspects of their social life is exerted to late blight management giving a new dimension to community reciprocity in managing contagious crop diseases. Table 5 illustrates how the proposal for mutual aid was modified at the same meeting with a scheme to use the money from fines to buy fungicides for the farmers.

Table 5: Learning to share fungicide cost of 'risk-causing' farmers.

Technical	"If all of us are not spraying on time as promised, we are spreading the disease." "My small field is at my backyard and far away from yours; do not worry about the disease." "Ababo, it was said the disease travels long distance even as far as Geba Robi (another village)."
Relational	"We cannot punish Ababo and Beyecha, they couldn't even save their potato, let alone pay the fine." "We should have discussed this when we set the rules." "But I suggested supporting each other or contributing money if anyone is in a problem."
Action	"Why don't we use the money that Gash (Mr) Negash is keeping?" "Good idea, let's use that money to buy Ridomil for both."

Analysis of communications around fungicide use as a late blight management option featured three different social learning outcomes. First, knowing late blight as a disease that spreads, as opposed to the predominant assumption that it is a weather problem, alerted farmers to bring the monitoring aspect not only to spraying but also to assess the performance of the existing monitoring committee and replace the members. Second, a new keenness to experiment with Mancozeb to avoid the potential metalaxyl resistance, encouraged the farmers to reconsider their stance on dealing with non-compliance and to propose and forge sanctioning mechanisms. Third, the practical insight that punishment could not guarantee compliance led to a decision to financially support farmers who had not complied. As can be seen from the quotes in Table 5, this decision was made because of the perceived late blight risk from unsprayed fields.

Using late-blight resistant varieties and clean seed potato

Learning on the multiple sources of late blight infection in general and infected potato tuber as an inoculum source, in particular, steered discussions around the use of healthy seed from resistant varieties to deal with late blight. New insight was made into the distinction between clean/disease-free seed and late-blight resistance varieties. Many farmers initially assumed that disease-resistant varieties would remain resistant to late blight. From some of the statements, this is partly attributed to the original framing of late blight as a weather problem. The realization that their widely grown varieties, such as

Gudene and *Jalene* once released as late blight resistant,[5] are no longer free from potato disease, led farmers to stress the importance of keeping their own seed clean from late blight. In this regard, proposals were made to undertake seed selection for the coming growing season, using a third-generation (G3) resistant variety (*Gudene*) for a positive selection.[6] Seed selection would be made with the help of an extensionist and a researcher from the Holeta Agricultural Research Center which would also provide the G3 seed.

Table 6: Learning towards collaboration with researchers on seed selection.

Technical	"My assumption was any seed that survived the weather problem is safe and I can use it as seed." "Yes, what we saved from the last harvest and planted this season may have late blight and other potato diseases." "Even if we use chemical, if we bring spoiled seed for next year, it is useless."
Relational	"We have to look for other clean seed sources." "We know that Holeta [research center] has quality seed but we don't get it here." "If we get clean seed from you, we will work to keep our seed clean. Our seed is infected with the disease now." "The problem is how can we check for a disease if the experts do not support us."
Action	"We can use the new seed from our learning plot but Lema [Holeta researcher] should teach and support us on the seed selection." "We will also practically learn how to do that from the researcher on the field." "Yes, once I [extensionist] get a good lesson, I am close to the farmers to continue supporting in seed selection and exchange."

The importance of keeping their own seed source free from late blight instigated reflections around the previous and potential future role of the district government agricultural office in seed quality checking. A few farmers, previously members of a seed-producing cooperative, had experience of working with the regional regulatory office and the district agricultural office in potato disease (Bacterial wilt) monitoring and seed potato marketing. They considered that this had been an unfair arrangement because only a few farmers with 'good relations' with the offices enjoyed the market benefits. Some of the other farmers seemed to know and embrace the stories and others appeared to be new to the details. Existing negative views about district offices and regulators were amplified by stories shared by former seed producers. The discussion led to a more restrictive proposal for a potential role for the district office in seed quality monitoring.

5 *Gudene* and *Jalene* are among the many late blight resistant varieties released by Holeta Agricultural Research Center over the years

6 Positive selection entails selecting healthy-looking, vigorous mother plants to obtain seed tubers for the next seasons' crop in a situation where there is a problem of availability of affordable disease free seed potatoes or resistant varieties (Schulte-Geldermann et al., 2012)

Table 7: Learning towards a restrictive role for district government offices in seed quality monitoring.

Technical	"Once we get disease-free seed, we will work to keep the seed free from late blight." "It is a similar work like Gind Atewelig (Bacterial wilt), few years ago district experts used to check the plant and the seed for Gind Atewelig."
Relational	"We [seed producers] were having such kind of [monitoring] experience. They used to plan and then visit the farms to check for the existence of Bacterial Wilt. But it was a bad experience." "The previous one and this one should not be the same. The reason is not the same; now the people gathered together, discuss and learn from one another but, at that time only few people used to come and tell us what to do." "The process was not transparent, and some farmers wanted to commit suicide from total rejection of their seed." "If it is going to be the same, I am not sure if I want to continue."
Action	"Let us use our own committee, we can monitor the disease on our own but you (facilitator) help us bring the experts to technically support us"

4

Communications around seed quality elicited two social learning outcomes. New insights on the distinction between healthy/clean and resistant variety and the contribution of farmers handling of seed to late blight prevalence opened new avenues for farmers to adjust their opinions about researchers from someone who failed to continually provide 'quality' seed to someone who can also assist in keeping farmers seed clean from the disease. This led to an agreement (Table 6) to seek researchers' support in seed selection and handling. The other learning outcome (Table 7) aligned discussions about the importance of seed quality checking with previous relation and collaborative practices with government district offices. Farmers advocated for a principally farmer-controlled seed monitoring approach, dismissing a potential role for the district agricultural office in seed quality monitoring.

Removing volunteers

Social learning in relation to removing volunteers as a late blight management method is stimulated by awareness of how volunteers (*Gebo*, namely potatoes growing after being left in the soil from the previous harvest) can be another source of late blight infection. Some farmers removed volunteers only when they wanted to plant another crop in a subsequent growing season but not because volunteers are an inoculum source for the pathogen. When another crop is not being planted, most farmers let the volunteers grow for a second-round harvest. Having realized the role of volunteers in pathogen spread, the issue of land contractual arrangements was raised by farmers who grow potato on a leased plot in a neighboring village. In the usual contractual agreement, the leasing farmers only harvest one time and must leave behind the volunteers for harvest by the property owners. Given the role of volunteers in pathogen spread, farmers proposed (Table 8) changing their contractual agreements to reduce volunteers. Table 9 also shows how the majority of farmers agreed to collectively implement the practice of removing volunteers from their own plot, irrespective of what they cultivate after potato.

Table 8: Learning to include the issue of control over volunteer plants in land contractual agreements.

Technical	"We don't remove Gebo if we plant potato as we wanted the tubers produced from the Gebo." "I think if we have to avoid the disease risk in our area, we should kill the Gebo."
Relational	"You can do that on your own plot but what about me who also work on rented land?" "That is right, we have to leave the produce from the Gebo to the landowner." "Why don't you teach them what you learned about the disease? They may agree." "It is not easy, I wish they could be here."
Action	"Let's try to discuss with the owners if they agree but they only care for their benefits." "It could be difficult for this season, but we should negotiate in the Belg [coming] season"

Table 9: Learning about joint monitoring of volunteer removal as a late blight management practice.

Technical	"When we plow the field, we only remove Gebo, so it will not remain there as a weed for the next crop." "But getting the disease is a higher risk." "Some of us still have Gebo or the tubers on our field and some just plowed and planted on it."
Relational	"We cannot do much about those who recently planted." "But most of us didn't plant yet and the committee should check as it is a disease problem."
Action	"This should be another activity for the committee to check before our next meeting." "Just call and let us [the Committee] know before you do it and we will check and report at the next meeting."

There were two social learning outcomes related to this late blight management practice. The first one relates with knowing volunteers as pathogen inoculum source that made farmers re-define existing practices and relationships in land contractual agreements. Second learning evidence is an agreement reached by more than half of the farmers to remove volunteers and to collectively monitor this practice. This time not because they see volunteers as a weed to another crop but because it can serve as inoculum source for the late blight pathogen.

Dehaulming

During the session, farmers learned that late blight can travel down from the plant (through the transfer of fungal spores) to the tuber when the haulm, comprising the aerial part of the plant, is not cut on time. However, this new insight did not lead to a learning outcome or any form of collective action in communication. Few farmers stated they had previously removed the haulm, believing it is good for tuber size and skin setting. However, they contended that the practice exposed their black soil (*Koticha*) which easily cracks and the tuber to direct sunlight, turning the tuber green. Given that some farmers considered that green tuber was a major reason for rejection at the market, the farmers decided not to introduce dehaulming as a management option unless there was a mechanism to avoid the change in tuber color. However, two farmers, who had no previous knowledge of the practice, said that they wanted to experiment with it on a small portion of their potato field to evaluate any effect on late blight infection or tuber color.

Linking social learning outcomes with collective action

Analysis of the discussion around different learning themes on late blight disease and its management revealed a total of nine social learning outcomes in the form of collective agreements related to an alignment of new communicated knowledge, discussed relations and suggested actions. Table 10 illustrates the extent to which the various agreements implicated in the discussions were implemented on the ground. From a process perspective, it can be observed that there is not a one-way relationship between a collective agreement and a collective action or that collective action comes necessarily after collective agreements. For instance, agreements to change the monitoring committee, to develop sanctioning systems or to share fungicide costs are informed by reflections from practical actions. In this sense, there was an iterative learning cycle whereby farmers contentiously modified or adapted their collective action by reflecting on their collective agreements and vice versa.

As can be seen in Table 10, two of the nine collective agreements could not be fully translated to collective action. For example, only about half of the field scout team did a regular joint visit to their farms. A possible explanation for this might be the problem of free-riding that is common in collective action problem situations. The free riding tendency by some farmers eventually led to a modification of the agreement around sanctioning mechanisms. The fact that farmers from nearby villages were not part of the collective agreement on amending land contractual arrangements for removing volunteers had influenced the translation of the agreement into action.

Table 10: Translation of collective agreements (social learning outcomes) into collective action.

Learning themes	Collective agreements	Collective actions
Late blight as a contagious disease	1. Agreement to bring on board other farmers that were not in the intervention	Farmers brought new fellow farmers in the community and the number of participating farmers grew from 21 to 33 during the time of the learning intervention. This is without the three farmers who departed after the second learning session.
	2. Agreement for team field scout and collective monitoring of late blight incidence	Farmers formed 11 field scout groups (3 neighboring farmers in a group) but the groups had different levels of success. About 6 of the groups scouted regularly while the others demonstrate different levels of irregularity. The irregularly made some groups cover for each other but pushed others to only scout their own field. Farmers also formed a monitoring committee composed of five people to interact with the scouting teams.
Fungicide use	3. Decision to replace members of the monitoring committee	As the committee failed to do proper monitoring after the reporting of disease incidence and the first round of spraying, farmers replaced four of the five initially selected committee members. The re-elected committee was active in collecting and sharing reports on late blight incidence and on-field monitoring of collectively agreed practices and reporting of results on reflexive meetings. Although all farmers agreed to practice seed selection and exchange, this activity was postponed to the next growing season as it needed access to clean seed from their own sources or a late blight resistant variety. A G3 seed of resistant variety (Gudene) was obtained from the Holeta Agricultural Research Center and planted to be used for this purpose.
	4. Agreement for sanctioning systems on non-compliance	Farmers developed and implemented a sanctioning system (money fines). They applied a fine of 100 Birr for a missing team field scout; 100 Birr (per scout team) for not reporting to the committee on prevalence of late blight; 50 Birr for missing learning and reflexive meetings. There were arguments between defectors and the committee on the first fines, the defectors finally skipped fines by making a public apology arguing it was the first time and that they would comply afterward. A total of eight people were fined at different times, totaling an amount of 650 Birr. Seven farmers skipped fines for bringing convincing social reasons (in the eyes of the committee) for not scouting and reporting.
	5. Agreement to share fungicide costs of 'risky' farmers	A fungicide (Ridomil) was bought for two farmers (a female and an old farmer) after late blight symptoms were detected on their field. It was not financed from shared money but from fines for non-compliance.
Using healthy seed and resistant varieties	6. Agreement to seek for researchers' support on seed selection	This was an activity planned for the next growing season as farmers had already prepared and some had even planted around the time of discussion on seed selection. However, seed selection with technical support from a Holeta researcher was made on the harvested G3 potato seed from the practical learning plot and distributed among the farmers to be positively selected and used as planting material for the next growing season.
	7. Decision to dismiss potential role for district government offices in seed quality monitoring	Farmers continued with a monitoring committee that was only composed of community members whereby trust issues played a major role in limiting options for potential collaboration in seed quality monitoring.
Killing volunteer plants	8. Agreement to include the issue of control over volunteer plants in land contractual agreements	Due to a relative land shortage in the area, seven farmers leased land for potato cultivation in a neighboring village. All the farmers that were growing potato on a rented plot had already made their contracts for 2-5 years during the growing season in which our learning intervention took place. However, three of these farmers discussed with their landowners the possibility of removing volunteers but the landowners rejected the idea.
	9. Agreement on joint monitoring of removing volunteer plants as a late blight management practice	The practice was monitored and 21 farmers out of 33 removed volunteer plants or collected remaining tubers in the soil before planting. While seven of them could not do this because of their contractual agreement, five farmers did not do it, saying hand removing the tuber is a laborious task.

Discussion

The study unraveled how social learning as a communication process in which new knowledge, relations and actions become aligned leads to collective agreements (first research question) and collective action (second research question) in the management of late blight. In answering the first research question, we discerned several communicatively agreed lines of action that were attended by communication regarding new knowledge, relations and actions. In this regard, new knowledge in relation to the threat posed by late blight as a contagious disease was instrumental in instigating discussions about relations and potential collective actions, thereby leading to several social learning outcomes. Although our review failed to find previous studies with a grounded perspective on late blight as a collective action problem, empirical studies of pest and invasive weed management highlighted that collective responses were effective when communities appreciate that the problem crosses farm boundaries and where benefits might arise from cooperation (Graham et al., 2018). A change in the framing of late blight by the community from a weather problem to a contagious disease involving pathogens fundamentally shifted awareness of late blight disease from a private bad to a collective bad. This, in turn, instigated social learning as new knowledge on the mobility and the contagious nature of late blight, linked to new perspectives on interdependency and proposals for collective action to manage the disease. The empirical study thus confirmed our assumption that disease management has particular features compared to the collective action problems generally studied in social learning literature. It differs from dominant social learning literature on collective action problems in natural resource management, migratory pests and invasive weeds which implicitly assume some sort of understanding of the collective nature of the problem, hence picks the role of social learning from there (Zamani et al,. 2018; Marshall, 2016; Brugnach et al., 2011; Toleubayev et al., 2007). The key role of technical knowledge in determining social learning outcomes is also demonstrated in a situation where farmers did not agree to implement dehaulming as a potential management practice, owing to their technical knowledge of the impact of direct sun on tuber quality[7]. We contend that attempts to develop and sustain collective action around diseases that are characterized by less visible dynamics should be supported with a strong learning element around the delicate life cycle and spreading mechanisms, demonstrating the interdependency of farmers. In addition, the contribution of social learning can be amplified if it takes a step back and firmly integrates such learning in a situation where there is ambiguity on the very collective nature of the problem.

However, a better understanding of the mobile nature of the disease was not sufficient reason for some of the farmers to cooperate in disease monitoring or to reach agreements

7 This change in tuber colour and quality is a well-known phenomenon in scientific literature as a production of a group of chemicals called glycoalkaloids that are toxic when consumed.

on the collective implementation of management practices. Their main argument was that they could individually control the late blight if they spray optimally, irrespective of the disease situation in the area. This finding is consistent with a case study on community-based resistant weed management whereby, despite knowledge of weed mobility, some community members perceived weed control as an individual problem by taking into account the economic costs (e.g. finance, labor) of managing resistance over time (Ervin and Frisvold, 2016). Similarly, lessons from situational studies on banana wilt and potato late blight in Central Africa and Ethiopia demonstrated that the public good features of a disease management strategy depend not only on specific agro-ecological properties of the disease but also on the available technological options and other community-specific social conditions and resources (Damtew et al., 2018; Leeuwis et al., 2018; McCampbell et al., 2018). This has an important implication for the framing of contagious crop diseases, such as late blight, as public bad mainly based on its mobility. We hope that this study triggers more in-depth scholarly discussions on what other biophysical, social or economic attributes, together with disease mobility, could be integrated to advance current theoretical perspectives that present contagious crop diseases as a public bad.

Communication about late blight as a shared risk played a key role in reaching agreement on collective action. This stimulated discussions on new types of social relationships for collective monitoring, including a committee and neighbor-to-neighbor field scouts. In this regard, the monitoring system performed two key relational functions: joint information collection and sharing on late blight incidence not only informed collective management activities but also leading to sanctions and new reciprocity as communities strove to deal with non-compliance. This mirrors the assessment by Ervin and Frisvold (2016) that when there is a shared understanding of the collective nature of the problem, interest can develop within communities in conducting monitoring and applying appropriate penalties when some operators do not comply with locally prescribed management practices. Even though farmers initially decided to implement monitoring, despite traditional superstition around letting others into their individual fields, they were not enthusiastic about sanctions. However, the fact that they eventually developed sanctioning systems and forged new ways of reciprocity through mutual aid in buying fungicides highlighted the observation by Ebuka et al., (2014) that social learning helps farmers to amend their perceptions of risks and their collective rules of engagement. In this regard, our research provided evidence that social learning can lead to the emergence of a rudimentary form of institutionalized coercion which can help to reduce overcome non-compliance in the management of contagious crop diseases, such as late blight. In a hypothetical game scenario, Zhang et al., (2013) similarly reported that 'toy-communities', guided by payoff considerations, started with a clear preference for the treatment without punishment but shifted to peer-punishment after a few rounds. We consider that the emergence and evolution of regulatory institutions through social learning has significant theoretical implications for the way scholars conceptualize social learning in the management of agricultural collective action problems in general and contagious crop diseases in particular. In this respect, a great majority of the reviewed literature on the subject appreciates regulatory institutions (e.g. monitoring, incentive mechanisms, graduated sanctions) from an institutional theory perspective, principally seeing it as an externally imposed system, rather than as something that can potentially emerge through social learning (e.g. Wulandari and Inoue, 2018; Hegde et al., 2016; Six et al., 2015; Christmann et al., 2015; Pahl-Wostl et al., 2009).

In relation to our second research question, our aim was to examine the influence of social learning on collective action in the management of late blight, focusing on the actual implementation of collective agreements. As can be noted from the results, while most farmers agreed that collective actions should be implemented, a few of these proposals could not be translated into action. For instance, farmers tied to property owners from a neighboring village via contracts could not translate the agreement to modify the rights to control volunteers into action. This relates to Ostrom's (1990) thesis on the importance of delineating clear boundaries between users and non-users of a resource. Although public good boundaries often have a gradient quality or are fuzzier (especially for highly mobile resources) than implied in the traditional public good design principles (Baggio et al., 2016; Cox et al., 2010), having a clear definition of geographical and institutional boundaries appears to be an important precondition for the translation of agreements into collective action. In this regard, unclear boundary definition for late blight management represented a missed opportunity for our social learning approach to inspire better cooperation between two seemingly different communities which are institutionally interrelated through land contractual agreements in potato cultivation. Although many of the agreements were physically implemented, there was visible non-compliance from some farmers, mainly on team scouting and on reporting on disease incidence.

Contrary to a range of evidence from public good studies, non-cooperating behavior of a few farmers did not seem to stop other farmers from complying with most of the collective agreements. This appears to provide some support for the conceptual premise of Ervin and Frisvold (2016) that farmers may still have an incentive to manage invasive or contagious crop problems and benefit from the adoption of practices, even when their neighbors do not and even when acting collectively is considered the best strategy.

This study showed how social learning, through aligned knowledge, relations and actions in communications, formed the basis for collective agreements and collective action. However, we are limited in being able to explain the translation from learning to action. Multiple factors may have influenced the extent of implementation of collective actions implicated in the social learning outcomes: levels of risk perception, information sharing/communication, production objectives, group heterogeneity, and resource boundary (Graham et al., 2018; Cox et al., 2010; Ostrom, 2010). In this regard, there is considerable scope for more research to explore and detail the different factors in action around the translation of collective agreements into actual practices on the ground.

Conclusion

We conclude that social learning and associated collective actions in the management of late blight are outcomes of an ongoing communication process with a range of interlinked technical, relational and action related issues. Outcomes of such a learning process can thus be made visible through the analysis of communicative processes. In this regard, the conceptualization of social learning in the management of contagious crop diseases would benefit from a broader view than what is commonly implied in the traditional social learning literature on natural resource management. This means, on the one hand, that conceptualization needs to strongly support community learning in relation to clearing ambiguities on the collective nature of the disease and, one the other, that this conceptualization needs to widen its scope for further systematic analysis of implementation of agreed collective actions. The crucial role of regulatory institutions in the management of public bads, such as late blight, also warrants social learning to embrace the emergence or evolution of such institutions in its conceptual and methodological approaches. We contend that social learning is a necessary precondition for collective action (the implementation of agreements in our case), but may not necessarily lead to it, given potentially multiple factors in operation. This interplay between social learning and collective action, specifically the role of different factors in the translation of agreements into practical action for the management of contagious diseases, requires further exploration.

References

Aarts N and Van Woerkum., 2008. Strategische communicatie [Strategic communication]. Assen, The Netherlands: Van Gorcum.

Amanda L, Brymer B, A. L., Wulfhorst JD and Brunson MW., 2018. Analyzing stakeholders' workshop dialogue for evidence of social learning. Ecology and Society, 23(1).

Baggio JA, Barnett AJ, Perez-Ibara I, Brady U, Ratajczyk E, Rollins N, Rubiños C, Shin HC, David J, Aggarwal R, John M. Anderies JM, and Janssen MJ., 2016. Explaining success and failure in the commons: the configural nature of Ostrom's institutional design principles. International Journal of the Commons 10(2), 417-439.

Beers PJ, Van Mierlo B and Hoes AC., 2016. Toward an integrative perspective on social learning in system innovation initiatives. Ecology and Society, 21(1).

Biedenweg K, Monroe M., .2013a. Teasing apart the details: how social learning can affect collective action in the Bolivian Amazon. Human ecology, 41(2), 239-253.

Biedenweg K, Monroe M., 2013b. Cognitive methods and a case study for assessing shared perspectives as a result of social learning. Society & Natural Resources, 26(8), 931-944.

Bouwen R, and Taillieu T., 2004. Multi-party collaboration as social learning for interdependence: developing relational knowing for sustainable natural resource management. Journal of community & applied social psychology, 14(3), 137-153.

Brugnach M, Dewulf A, Henriksen HJ and Van der Keur P., 2011. More is not always better: coping with ambiguity in natural resources management. Journal of Environmental Management 92(1), 78-84

Campilan D., 2002. Linking social and technical components of innovation through social learning. Wheelbarrows Full of Frogs: Social Learning in Rural Resource Management. Assen, The Netherlands, 135-146.

Cáceres PA, Pumisacho M, Forbes G, and Andrade Piedra, JL., 2008. Learning to Control Potato Late Blight-A Facilitator's Guide. International Potato Center.

Cárdenas JC, Rodriguez LA, and Johnson N. 2015. Vertical collective action: addressing vertical asymmetries in watershed management. Documento CEDE, (2015-07).

Christmann S, Aw-Hassan A, Rajabov T, and Rabbimov A., 2015. Collective action for common rangelands improvement: a climate change adaptation strategy in Uzbekistan. Society & Natural Resources, 28(3), 280-295.

Cox M, Arnold G and Villamayor TS., 2010. A review of design principles for community-based natural resource management. Ecology and Society 15 (38).

Damtew E, Tafesse S, Lie R, van Mierlo B, Lemaga B, Sharma K, Struik PC, and Leeuwis C., 2018. Diagnosis of management of bacterial wilt and late blight in potato in Ethiopia: A systems thinking perspective. NJAS-Wageningen Journal of Life Sciences, 86, 12-24.

Davies B, Blackstock K, Brown K, Shannon P (2004) Challenges in creating local agri-environmental cooperation action amongst farmers and other stakeholders. The Macaulay Institute, Aberdeen.

4

Deuffic P and Candau, J., 2006. Farming and landscape management: how French farmers are coping with the ecologization of their activities. Journal of Agricultural and Environmental Ethics, 19(6), 563-585.

Ervin DE and Frisvold GB. 2016. Community-based approaches to herbicide-resistant weed management: lessons from science and practice. Weed Science, 64(SP1), 609-626.

Ford JD., 1999. Organizational change as shifting conversations. Journal of Organizational Change Management, 12(6), 480-500.

Gee JP and Green JL., 1998. Chapter 4: Discourse analysis, learning, and social practice: A methodological study. Review of research in education, 23(1), 119-169.

Gerritsen AL, Stuiver M, Termeer CJ., 2013. Knowledge governance: An exploration of principles, impact, and barriers. Science and Public Policy, 40(5), 604-615.

Graham S, Metcalf AL, Gill N, Niemiec R, Moreno C, Bach T, Ikutegbe V, Hallstrom L, Ma Z, Lubeck A., 2019. Opportunities for better use of collective action theory in research and governance for invasive species management. Conservation Biology, 33(2), 275-287.

Guchi E., 2015. Disease management practice on potato (Solanum tuberosum L.) in Ethiopia. World Journal of Agricultural Research, 3(1), 34-42.

Hardin R., 2015. Collective action. Resources for the Future Press. Baltimore, MD: Johns Hopkins University Press.

Heffernan C, Nielsen L, Thomson K, Gunn, G., 2008. An exploration of the drivers to bio-security collective action among a sample of UK cattle and sheep farmers. Preventive veterinary medicine, 87(3-4), 358-372.

Hegde N, Elias M, Lamers HA, and Hegde M., 2017. Engaging local communities in social learning for inclusive management of native fruit trees in the Central Western Ghats, India. Forests, Trees and Livelihoods, 26(1), 65-83.

Ibuka Y, Li M, Vietri J, Chapman GB, and Galvani AP., 2014. Free-riding behavior in vaccination decisions: an experimental study. PloS one, 9(1), e87164.

Joss S and Brownlea A.,1999. Considering the concept of procedural justice for public policy-and decision-making in science and technology. Science and Public Policy, 26(5), 321-330.

Kassa B and Beyene H., 2001. Efficacy and economics of fungicide spray in the control of late blight of potato in Ethiopia. Afr. Potato Sci. J. 9 (1), 245–250.

Koontz M., 2014. Social learning in collaborative watershed planning: the importance of process control and efficacy. Journal of Environmental Planning and Management 571(0), 1572-1593.

Lamerichs J and Te Molder H., 2002. The delicate discourse of support. Wheelbarrows Full of Frogs. Social Learning in Rural Resource Management: International Research and Reflections. Assen, The Netherlands, 301-14.

Leeuwis C, Cieslik K, Aarts N, Dewulf, A, Ludwig F, Werners SE, Struik PC., 2018. Reflections on the potential of virtual citizen science platforms to address collective action challenges: Lessons and implications for future research. NJAS-Wageningen Journal of Life Sciences, 86, 146-157.

Leeuwis C and Aarts N., 2011. Rethinking communication in innovation processes: creating space for change in complex systems. Journal of agricultural education and extension, 17(1), 21-36.

Leeuwis C, and Pyburn R., 2002. Concluding reflections on social learning. Wheelbarrows Full of Frogs: Social Learning in Rural Resource Management: International Research and Reflections. Assen, The Netherlands, 449-470.

Leeuwis C, Pyburn, R., 2002. Social learning for rural resource management. Wheelbarrows full of frogs: social learning in rural resource management: international research and reflections, 11-24.

Loorbach D (2007) Transition management: new mode of governance for sustainable development. International Books, Utrecht, The Netherlands.

Marshall G, Coleman MJ, Sindel BM, Reeve IJ, Berney PJ., 2016. Collective action in invasive species control, and prospects for community-based governance: the case of serrated tussock (Nassella trichotoma) in New South Wales, Australia. Land Use Policy 56:100–111.

Marshall G (1998) A dictionary of sociology. Oxford University Press, New York.

McCampbell M, Schut M, Van den Bergh I, Van Schagen B, Vanlauwe, B, Blomme G, Gaidashova SV, Njukwe E, and Leeuwis C., 2018. Xanthomonas Wilt of Banana (BXW) in Central Africa: Opportunities, challenges, and pathways for citizen science and ICT-based control and prevention strategies. NJAS-Wageningen Journal of Life Sciences, 86, 89-100.

Meinzen-Dick R, Di Gregorio M, McCarthy N., 2004. Methods for studying collective action in rural development. Agric Syst 82(3):197–214

Mekonen S, Alemu T, Kassa B, and Forbes G., 2011. Evaluation of contact fungicide spray regimes for control of late blight (Phytophthora infestans) in southern Ethiopia using potato cultivars with different levels of host resistance. Tropical Plant Pathology, 36(1), 21-27.

Mesfin T, Woldegiorgis G., 2007. Impact of farmers' selected idm options on potato late blight control and yield. In 8th African Crop Science Society Conference, El-Minia, Egypt, 27-31 October 2007 (pp. 2091-2094). African Crop Science Society.

Miller JS, Nolte P, Olsen N, Miller T, Bohl B, Thornton M., 2006. Late Blight Management Action Plan for Potatoes. University of Idaho Extension.

Miranowski JA and Carlson GA., 1986. Pesticide Resistance: Struteyies and Tuctics for Management, National Academy Press, Washington, DC.

Mostert E, Pahl-Wostl C, Rees Y, Searle B, Tabara D, and Tippet J., 2007. Social Learning in European River-Basin Management: Barriers and Fostering Mechanisms from 10 River Basins. Ecology and Society 12(1): 19.

Olson M., 1971. The Logic of Collective Action: Public Goods and the Theory of Groups. Cambridge, MA: Harvard University Press.

Ostrom E., 2010. Polycentric systems for coping with collective action and global environmental change. Global Environmental Change 20:550–557.

Ostrom E., 1990. Governing the Commons – the Evolution of Institutions for Collective Action, New York: Cambridge University Press.

Pahl-Wostl C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environmental Change, 19(3), 354-365.

Pahl-Wostl C., 2000. Towards sustainability in the water sector: the importance of human actors and processes of social learning. Aquatic sciences, 64(4), 394-411.

Pahl-Wostl C and Hare M., 2004. Processes of social learning in integrated resources management. Journal of Community & Applied Social Psychology, 14(3), 193-206.

Pahl-Wostl C, Craps M, Dewulf A, Mostert E, Tabara D, Taillieu T., 2007. Social learning and water resources management. Ecology and society, 12(2): 5.

Phuong LTH., 2017. Developing adaptive capacity in times of climate change in central rural Vietnam: exploring smallholders' learning and governance (Doctoral dissertation, Wageningen University).

Poteete A, Janssen M, and Ostrom E., 2009. Multiple methods in practice: collective action and the commons. Multiple methods in practice: collective action and the commons. Princeton University Press, Princeton, New Jersey, USA.

Pretty J., 2003. Social capital and the collective management of resources. Science, 302(5652), 1912-1914.

Reed M, Evely AC, Cundill G, Fazey, IR, Glass J, Laing A, Newig J, Parrish B, Prell C, Raymond C, and Stringer L (2010) What is social learning? Ecology and Society, 15(4): 4.

Rist S, Chiddambaranathan M, Escobar C, Wiesmann U., 2006. "It was hard to come to mutual understanding…"—the multidimensionality of social learning processes concerned with sustainable natural resource use in India, Africa and Latin America. Systemic Practice and Action Research, 19(3), 219-237.

Rodela R., 2013. The social learning discourse: Trends, themes and interdisciplinary influences in current research. Environmental science & policy, 25, 157-166.

Roling NG, and Wagemakers MA (Eds)., 2000. Facilitating sustainable agriculture: participatory learning and adaptive management in times of environmental uncertainty. Cambridge University Press.

Ruiz JR., 2009. Sociological discourse analysis: Methods and logic. In Forum qualitative sozialforschung/Forum: Qualitative social research, Vol. 10, No. 2

Senge P., 2006. The Fifth Discipline: The Art and Practice of the Learning Organization (Revised and Updated Edition). Doubleday, New York.

Scholz G, Dewulf A, and Pahl-Wostl C., 2014. An analytical framework of social learning facilitated by participatory methods. Systemic Practice and Action Research, 27(6), 575-591.

Schusler TM, Decker DJ, and Pfeffer MJ., 2003. Social learning for collaborative natural resource management. Society & natural resources, 16(4), 309-326.

Schulte-Geldermann E, Gildemacher PR, and Struik PC., 2012. Improving seed health and seed performance by positive selection in three Kenyan potato varieties. American Journal of Potato Research, 89(6), 429-437.

Six B, Zimmeren van E, Popa F, and Frison C., 2015. Trust and social capital in the design and evolution of institutions for collective action. International Journal of the Commons, 9(1), 151-176.

Tafesse S, Damtew E, van Mierlo B, Lie R, Lemaga B, Sharma K, Leeuwis C,and Struik PC., 2018. Farmers' knowledge and practices of potato disease management in Ethiopia. NJAS-Wageningen Journal of Life Sciences, 86, 25-38.

Te Molder H, and Potter J., 2005. Conversation and cognition. Cambridge University Press.

Toleubayev K, Jansen K, and van Huis A., 2007. Locus control in transition: the loss and reinvention of collective action in post-Soviet Kazakhstan. Ecology and Society 12:38.

Tsedaley B., 2014. Late blight of potato (Phytophthora infestans) biology, economic importance and its management approaches. J. Biol. Agric. Health. 25, 215–226.

Uetake T., 2012. Providing agri-environmental public goods through collective action: lessons from New Zealand case studies. Paper presented at the 2012 NZARES Conference, Tahuna Conference Centre—Nelson, New Zealand. August 30–31

Van Der Stoep H, Aarts N, and Van Den Brink A., 2017. Shifting frames: mobilizing policy attention for landscape values in a Dutch urban–rural fringe. Journal of Environmental Policy & Planning, 19(6), 697-711.

Woodhill J., 2010. Sustainability, social learning and the democratic imperative: Lessons from the Australian Landcare movement. In Social learning systems and communities of practice (pp. 57-72). Springer, London.

Wulandari C, and Inoue M.,.2018) The Importance of Social Learning for the Development of Community Based Forest Management in Indonesia: The Case of Community Forestry in Lampung Province. Small-scale Forestry, 17(3), 361-376.

Zamani N, Bazrafkan K, Minaei K., 2018. Understanding grower non-participation in the collective management of carob moth in pomegranate in Iran. NJAS-Wageningen Journal of Life Sciences, 85, 42-49.

Zhang B, Li C, De Silva H, Bednarik P, Sigmund K., 2014. The evolution of sanctioning institutions: an experimental approach to the social contract. *Experimental Economics*, *17*(2), 285-303.

4

5

Chapter 5

Communicative interventions for collective action in the management of potato late blight: Evidence from a framed field game experiment in Ethiopia[22]

[22] Submitted to food security journal as Damtew, E., Leeuwis, C., Struik, P.C., Francesco, C., van Mierlo, B., Lie R., Lemaga B, Cieslik, K.
Communicative interventions for collective action in the management of potato late blight: Evidence from a framed field game experiment in Ethiopia

Abstract

Potato late blight remains a threat to food security and livelihood of millions of people in Ethiopia. Despite a rapid dispersal of the disease pathogen and farmers' interdependency in managing it, the literature on agricultural extension and communication tends to frame the disease and its management as a problem of the individual farmer. This study appreciates late blight as a collective action problem whose management requires a corresponding re-configuration in information sharing and communicative practices. We employ a framed field game experiment with a mixed quantitative and qualitative method to explore how and to what extent different types and combinations of communicative interventions affect collective action in the management of the disease among farmers in Ethiopia. Interestingly, our quantitative findings revealed that the provision of technical information about interdependency involved in the management of the disease, and monitoring information about the management practices of other farmers negatively affected collective action. However, collective action performance significantly improved when farmers were given the opportunity to interactively communicate about their management strategies. Further qualitative investigation sheds light on how farmers used and made sense of the different communicative interventions to inform and adjust their individual decisions, coordinate collective strategies, pressure free-riders and develop a shared identity. It is concluded that interventions that mainly promote the provision of technical and social information can be counterproductive in managing collective action problems such as late blight unless it is complemented with interactive communication and deliberation processes.

Keywords:

Potato late blight, Collective action, Communicative intervention, Information, Interdependency; Smartphones

Introduction

Potato late blight, caused by *Phytophthora infestans* (Mont.) de Bary, is the major bottleneck in potato production, a crop that holds promise for food security and livelihood improvement to millions of people in Ethiopia (Demissie, 2019; Tsedaley et al., 2014). Since late blight came to the spotlight for being the cause of the Irish potato famine in the 1840s, it has been the most studied (and still among the most destructive) potato diseases in many parts of the world (Campos and Ortiz, 2019; Kirt et al., 2014). The disease develops and spreads rapidly under high relative humidity, moderate temperature, and substantial rainfall and has the potential to destroy the whole potato field within a few days (Burke, 2017; Kirt et al., 2014).

Rooted in traditional agricultural extension and technology adoption model (Rogers, 1995), communicative research and development interventions to deal with the problem of late blight have a tendency to frame the disease as a problem of the individual farmer. This is reflected in interventions that advocate a linear form of advisory approaches geared towards the promotion of adoption of disease management technologies and practices at the level of individual farmers or households (Pernezny et al., 2014; Tsedaley, 2014; Bekele et al., 2012; Kassa, 2012; Mekonen et al., 2011; Miller et al., 2006; Franc, 1998). There is a normative expectation that something considered desirable can spread across a larger number of users (Peng et al., 2018; Leeuwis, 2010). Nevertheless, recent studies in a resource-poor smallholder farmer context stress that the rapid dispersal of the late-blight pathogen across farm boundaries gives the management of the disease a collective action problem feature (Damtew et al., 2018; Tafesse et al., 2018). Meaning, lack of control of the disease by any individual farmer imposes costs or losses on other nearby farmers and likewise, control efforts by one farmer can confer a benefit to other nearby farmers (Graham et al., 2019; Bell et al., 2016). Because of this characteristic of the disease and its causing agent, the management of late blight is regarded as one among specific types of collective action problems in the domain of 'public bads' (e.g. infectious and invasive species, microbial resistance to antimicrobial agents, global warming, air pollution) (Costello et al., 2017).

In a broader sense, a collective action problem is a situation in which all individuals would be better off cooperating but fail to do so because of conflicting interests between individual and collective goals (Olson, 2009). The role of information and communication in overcoming collective action problems has been highlighted in seminal papers (Ostrom, 1992; Ostrom and Walker, 1991; Sell and Wilson, 1991) and more recent literature, mainly in the field of behavioral economics (Cabrales et al. 2016; Reuben and Riedl, 2013; Smith, 2010; Milinski et al., 2008; Cardenas et al., 2004; Cardenas and Ostrom, 2004). In fact, Sell and Wilson (1991) argued that information and communication are among the most important factors to influence cooperative behavior among interdependent individuals in a collective action problem situation. In this regard, many game-based experimental studies have been conducted in laboratory and field settings to study how the provision of monitoring information (about practices of others) and/or group communication influence collective action among interdependent individuals. However, literature in the field of behavioral economics has put emphasis on monitoring information with limited attention to other types of information that could highlight interdependency originating from the ecological characteristics of the collective action problem at hand. For instance, Steingrover et al. (2010) emphasized that information about the multiple biophysical features (e.g. pest and disease dynamics in crops, landscape services, habitat for biodiversity and antagonists) is a potentially powerful way of illuminating interdependencies and the need for collective action among members of a community. Similarly, the provision of technical information about interdependency in relation to the collective risk and benefits of individual management practices can play an important role in influencing collective action in the management of the disease. As a separate research topic, a large body of experimental evidence exists on the role of group communication in overcoming collective action problems. What is largely missing in the latter domain of research is a systematic investigation of the underlying mechanisms that can give a robust explanation of how or why group communication influences collective action.

As further conceptualized and argued in detail in section 2, this study designed a framed field game experiment that brought together three different types of communicative interventions to stimulate collective action in the management of potato late blight in Ethiopian. The first intervention was to provide technical information about interdependency in managing the disease (fungicide spraying). The second intervention added monitoring information, that is, information about the practices of other farmers. The third intervention added a group communication element that gave space for farmers to interactively communicate about their collective problem and its management.

Given the increased availability of ICTs (Information and Communication Technologies) in rural settings and their presumed ability to facilitate network formation, dialogue and learning, there is also a growing research interest in experimenting with different communicative and informational functions in collective action problem situations using such technologies (Cieslik et al., 2018; Bennet and Segerberg, 2012). Mobile phones and related technologies can particularly play meaningful roles in facilitating communication among spatially and temporally distributed individuals (Bennet and Segerberg, 2012). Correspondingly, the group communication (third intervention) was supported by an internet-supported smartphone application (Voxer) that enabled farmers to communicate through voice and text messages. Farmers were given smartphones and had the opportunity to talk to each other about their individual or collective strategies to deal with their collective problem.

This study is primarily interested in understanding how and to what extent the different types of communicative interventions influence farmers' collective action in the management of potato late blight. In doing so, it also assesses the potential advantages and disadvantages of using smartphones as a platform for group communication.

The paper proceeds as follows. Section 5.2 further details the theoretical argumentation that led to our specific hypotheses and research inquiries. Section 5.3 covers the methodology in which the experimental design, the experimental procedure, the game framing, and the quantitative and qualitative data analysis approaches are presented. The results of the study are reported in Section 5.4. Sections 5.5 and 5.6 presents the discussion and conclusion part, respectively.

Literature review and hypotheses

Communicative interventions in collective action problems

Communicative intervention is the professional use of communication to help resolve problematic situations or to achieve societal ends (Leeuwis and Aarts, 2011; Leeuwis, 2004). In the context of crop disease management in general, and that of late-blight prevention and control in particular, the dominant form of communicative intervention has been agricultural extension (Pande et al., 2009; Ciancio and Mukerji, 2008). This includes practices like advisory communication, information provision and persuasive campaigns using different media and channels. These types of linear and expert-driven communicative practices are informed by early adoption theories and social-psychological models that aim to influence clients' innovation decisions in a direction deemed desirable by a communication intervener (e.g. Rogers, 1995; Petty and Cacioppo, 1986). Such individualistic perspectives have been criticized for their simplistic notion of adoption decision and the lack of attention for social and institutional dimensions of innovation (Leeuwis, 2004). This is a limitation in view of the fact that late-blight management is a collective action problem as farmers are interdependent in their efforts in managing the disease. More in general, it has been argued that rural innovation has collective dimensions and that other forms of communicative intervention or innovation intermediations are needed (e.g. facilitation of learning or space for negotiation, conflict management and everyday communication) (Leeuwis, 2004). Communication interventions can have broader roles than providing information-based advisory services or applying persuasive strategies that are aimed at influencing individual behavior (Klerkx et al., 2009; Klerkx and Leeuwis, 2008). Such innovation scholars, however, mostly look at collective dimensions and new forms of communicative interventions in terms of resolving coordination in multi-stakeholder settings (e.g. among actors in value chains, niches or regimes). They have not particularly looked at the specific communicative challenges in collective action situations or in the management of public bads that involve interdependent individuals. Therefore, we test several communicative interventions on their influence on collective action among interdependent farmers.

In the context of collective action problems, a communicative intervention can be designed around the provision of information with the aim of explicating the ecological features of the disease management problem that makes individuals interdependent (Peng et al., 2018; Ostrom, 1999). Costello et al. (2017) argued that knowing the spatial connectivity induced by the mobility of public bad resources influences private decisions, which collectively can have important consequences for control across a spatial domain. In our study context farmers have very limited knowledge of the spreading feature of the late-blight pathogen and the collective risk and benefit of individual management decisions (Damtew et al., 2020; Tafesse et al., 2018). In this regard, evidence from a systematic investigation of the role of such type of communicative intervention in collective action problems is sparse. The first hypothesis is that knowing or having technical information on the interdependency that originates from the collective risk and benefit of the individual management practice could positively contribute to farmers' collective action or cooperation in managing late blight.

Hypothesis 1: Providing technical information about interdependency resulting from the collective risks and benefits of individual management practices will improve collective action among farmers in managing late blight.

Communicative interventions can also be designed around the provision of monitoring[1] information on practices of others involved in the management of collective action problems (Khadjavi et al., 2017; Martin et al., 2014; Miliniski et al., 2008). There exists a large body of experimental literature in the economics field that attempted to examine the role of monitoring information in collective action. A key motivation for these studies has been the underlying assumption of complete information in earlier experimental studies and the subsequent criticism of such an idealized hypothetical scenario to not adequately reflect the types of uncertainty that people face in real-life (Choi and Lee, 2014; Andreoni and Petrie, 2004). It is contended that in reality decision-makers operate in a limited information environment or do not always have information on what others are doing to use the information as a reference point for future decisions (Martin et al., 2014; Andreoni and Petrie, 2004). In this respect, evidences from a range of experimental studies presented inconsistent findings whereby some showed a positive effect of monitoring information on collective action (Khadjavi et al., 2017; Janssen et al., 2010; Smith, 2010; Crawford, 1998), whereas others found no effect (Hashim et al., 2011; Marks and Croson, 1999; Weimann, 1994; Sell and Wilson, 1991). This would mean that monitoring information needs to complement technical information about interdependency to overcome collective action problems. We test this assumption with two hypotheses:

1 Different terms like 'Information', 'Behavioral information', 'Decision information' are used in the economics literature.

Hypothesis 2: Providing monitoring information on the management practices/decisions of others as well as technical information to make farmers aware of their interdependency will further enhance collective action among farmers.

Moreover,

Hypothesis 3: The role of monitoring information on collective action is influenced by whether or not farmers have technical information about interdependency.

A separate strand of economics literature has its focus on understanding the role of group communication or 'cheap talk' on collective action. By creating a sort of a discursive space, the opportunity to communicate is viewed as a mechanism that enables individuals to discuss, negotiate or coordinate strategies to deal with their collective action problem (Balliet, 2010; Dietz et al,. 2003; Marks and Croson, 1999; Ostrom, 1992). A number of experimental studies reported a positive effect of communication on collective action (Cason et al., 2012; Bachi et al,. 2010; Smith, 2010; Bochet et al., 2006). However, taking into account the wider intermediary role of a communicative intervention, none of the reviewed literature made an attempt to integrate and investigate the effect of group communication together with the other types of communicative interventions (provision of monitoring information and technical information about interdependency) on collective action. Accordingly, we hypothesize that:

Hypothesis 4: An opportunity to communicate on top of monitoring information on practices of others and technical information about interdependency will result in the highest level of collective action in managing late blight.

Beneath the relationship between communicative interventions and collective action

Previous experimental studies are rarely supported with explanations of the mechanisms underpinning the relationship between communicative intervention and collective action. There is a limited evidence-based account of how or why a particular communicative intervention contributed to the observed variations in collective action. In this regard, we propound that a deeper examination of the role of communicative interventions in collective action problem situations is of considerable scientific and practical relevance. Some plausible explanations are suggested in literature as to how a group communication, as one specific type of communicative intervention, can influence collective action behavior. First, communication provides the opportunity to coordinate a collective strategy through clarifying confusion and facilitating discussions on incentives and trade-offs between individual and collective goals. Second, communication can also help people offer or extract promises of cooperation and detect and pressure free-riding behaviors. A third explanation is that communication permits subjects to create or reinforce a sense of group identity that could help motivate cooperative behavior (Peng et al., 2018; D'Exelle et al., 2012; Garicano and Wu, 2012; Balliet, 2010; Cardenas et al., 2004; Dietz et al., 2003). Informed by these perspectives on group communication and other emergent themes for the other types of communicative interventions, this study qualitatively explains how our communicative interventions influenced collective action behaviors in the management of late blight.

Similarly, in any type of communicative intervention, the medium of communication potentially has a number of enabling or constraining functional qualities (Leeuwis, 2004). As our group communication was supported with an internet-enabled smartphone application, we are further interested in assessing the implication of using the platform as part of the wider role of the group communication environment. This means that our focus is not to investigate the contribution of the platform to collective action performance. Instead, our interest lies in assessing specific challenges, advantages or disadvantages of using the platform as one type of communication channel when farmers communicate to coordinate their strategies or pressure free-riding behavior or create/develop a shared identity in the management of their collective problem.

Methodology

The study is based on a mixed quantitative and qualitative analysis of a framed field game experiment conducted with real-life potato growers suffering from potato late-blight disease. In line with the order of our research inquiry, the methodology section has two major sub-sections. The first sub-section (5.3.1-5.3.3) covers the quantitative part on the experimental design and procedure, the game framing, the data source and method of analysis. The second sub-section (3.4) describes the data collection and analysis for the qualitative part of the study.

Experimental design

Our experiment simulated the management of potato late blight as a collective action problem whereby farmers have to make individual decisions/actions to spray or not to spray their own field but their level of success to control the disease depends not only on their individual action but also on the actions of other neighboring farmers. It was hypothesized that the proportion of farmers that are in a group meeting the threshold (level of collective action) would be different for the types of communicative interventions.

Four experimental conditions were used to investigate how farmers respond to the different types of communicative interventions. Hence, the roles of the different types of communication interventions were tested under four intervention conditions against a non-intervention condition.

1. In the non-intervention, farmer groups were not provided with any of the information types (technical information and monitoring information) and were not given the opportunity to communicate with each other.

2. In the 1st intervention, the farmer groups were provided with technical information about interdependency or the collective risk and benefit of individual spraying practices (*Hypothesis 1*).

3. In the 2nd intervention, the farmer groups were provided with technical information about interdependency and monitoring information on the spraying decisions of others (*Hypothesis 2*).

4. In the 3rd intervention, the farmer groups were only given monitoring information on the spraying decisions of others (*Hypothesis 3*).

5. In the 4th intervention, on top of technical information about interdependency and monitoring information, the farmer groups had the opportunity to communicate with each other (*Hypothesis 4*).

Table 1: Conditions .

Non-intervention	No Technical information; No Monitoring information; No Communication
Intervention 1	Technical information
Intervention 2	Technical information and Monitoring information
Intervention 3	Monitoring information
Intervention 4	Technical information; Monitoring information; Communication

A total of 225 farmers were involved from the Wolmera district in the central highlands of Ethiopia. Out of the 23 rural kebeles[2] in the district, Nine kebeles with extensive potato production were purposely selected. From a list of all villages (*got'es)* within a kebele, five villages were then randomly drawn. Finally, five farmers were randomly selected from all inhabitants of each village making a total of 25 participant farmers from each kebele. The farmers from one village were distributed randomly over the five intervention and non-intervention groups. In this way, we reduced a potential bias we could have encountered if neighboring farmers in the non-communicating group would have a chance to physically identify each other, hence communicate. Thus each intervention and non-intervention condition was tested with 45 farmers (9 groups of five farmers) from the diverse kebeles.

2 The smallest official government administrative unit in Ethiopia

Implementation procedure

The experiment was conducted in the nine kebeles one after the other and each experiment or game session took three days per kebele following a standard procedure. First, the objective of the experiment was explained and farmers' willingness to participate was obtained. It was also made clear to them that if they happen to be in the communication intervention group, their conversation would be recorded on the smartphone for a research purpose and this was confirmed with a consent form. Farmers from the same village then drew a lottery to go into the different intervention and non-intervention groups and were given a unique identifier. All participants from all groups were then administered with a registration checklist containing general socio-economic and potato production practice-related questions. Two parallel information-sharing sessions that approximately took 45 minutes were held with farmers in all intervention and non-intervention groups. The session for intervention 1, intervention 2 and intervention 4 was about the interdependency originating from the collective risk and benefit of individual management practices. The session with farmers in the non-intervention and intervention 3 was on potato nutrition a topic with little connection to their fungicide spray decision making choices. All the farmers then came together for a chart-based explanation on the game framing as detailed in sub-section 3.3.

Game framing

Farmers were informed that they would be compensated for their time in the game, they were guaranteed to take home 600 Ethiopian Birr (about 22 USD then), and in the best-case scenario, they could take home 1200 ETB. It was explained that they were going to participate in a game where they all played themselves as potato farmers. It was emphasized that late blight is a disease that can spread from field to field, as it is air-borne, and any unsprayed field at the time of disease occurrence would be a source of infection to neighboring fields. In reality, all farmers spray fungicide to control late blight and the point of the game was for them to decide about fungicide spraying which is a real-life investment that they make to control the late-blight disease. They could choose not to spray, to spray once, twice, thrice or four times during the whole game. The game with four rounds was assumed to represent one potato growing season as farmers also make multiple spraying decisions in a particular growing season. They were informed that the game was played in a group of five people that were anonymous to each other and the group success in managing late blight depended not only on the decision of the individuals but also on the decisions of others in the group.

Before the first game round, everyone received an initial endowment of 600 ETB which symbolized the amount of money they spent to buy the required quantity of fungicide in a particular growing season. If their decision was to spray, they needed to put a 100 ETB note in an envelope and secretly put it in a ballot box. If they chose not to spray, they would submit an empty envelope.

If a group reached a total investment of 1500 ETB by the end of the fourth round, it meant that they managed to protect their field from late blight. If their investment was below 1500 ETB, the disease hit and caused damage. After the end of the fourth decision, there would be a harvest time that depended on their individual and group contribution or the number of fungicide application.

1. When a group managed to reach the threshold of 1500 ETB, every player received an extra 600 ETB as a 'successful harvest' money. Every player also kept the money they had left from their initial endowment of 600 ETB. For instance, if a farmer sprayed only two times (200 ETB) and his group controlled the disease, he would receive 600 ETB harvest money and also kept his remaining 400 ETB taking home a total of 1000 ETB. In this way, the amount of 'take-home' money could differ between farmers based on their spraying decision creating a dilemma situation.

2. When a group did not reach the threshold of 1500 ETB, it meant that the spraying was not enough, the late blight hit the crop and their harvest was affected. In such a case, if an individual in a group sprayed four times, it meant that s/he managed to control the late blight a bit and his/her harvest got him/her 400 ETB. Three times spraying got him/her 300 ETB. Two times spraying got him/her 200 ETB. One time spraying got him/her 100 ETB. Zero spraying got him/her nothing or 0 ETB. Although the harvest money of individuals in a losing scenario depended on the number of individual sprayings, they also kept the money left in their pocket at the end and everyone finally took home 600 ETB. Apart from a way of compensating farmers for participating in the game, this was with the assumption that farmers, as rational decision-makers, normally aim for controlling the disease (get better harvest). However, they still have a dilemma situation or an incentive to free-ride and save more money in their pocket with the hope that other group members might contribute enough to control the disease.

After the explanation, all participants, with the exception of the communicating groups, went straight to making their first spraying decision. The communicating groups were separately given a small hands-on training on the use of the smartphones, the group communication app (Voxer) with a nudge that if they saw a need they would have a chance to communicate within their group members about the game. The communication groups then went to their first round of decisions.

The first decision was made on the first day, the second decision on the morning of the second day, the third decision in the late afternoon of the second day and the last decision was made on the morning of the third day. Unlike the conventional multiple round game procedure (Miliniski et al., 2008) where each round continued right after the former, we let players have at least eight hours between rounds so that farmers in the communicating group would have the opportunity to communicate if they saw the need. After each round of the game, only players in intervention 2, 3 and 4 were individually given monitoring information or information on the decision of others in their group.

Quantitative data and analysis

Spraying decisions of 225 farmers from all intervention and non-intervention groups were used as the data source for the quantitative analysis. Within the different intervention and non-intervention groups, if a farmer was in a group that reached the threshold of 1500 ETB after 4 rounds of spraying decisions, s/he was given a value of 1 and if s/he was in a group that did not meet the threshold after 4 rounds of spraying decisions, s/he was given a value of 0. Accordingly, we had 225 data points produced from a total of 900 spraying decisions. The effect of the four interventions (interventions 1, 2, 3 and 4) was compared relative to the non-intervention group. To improve the precision of our estimates, the measurement of the effect of the different interventions was controlled for individual attributes (*age, sex, education, household size, potato farm size, perceived late-blight seriousness, mainly seed producer, mainly ware producer, mobile phone ownership, and smartphone ownership*) and kebele fixed effects. We used multiple linear regression to estimate our outcome variable which was the likelihood of reaching a goal (threshold) to control late blight under the different communicative intervention conditions. The model used to estimate reads:

$$Y_i = C + \alpha T_i + \beta X_i + K + \varepsilon_i$$

Where Y_i is the value of the threshold variable for respondent i, T_i is the intervention dummy, C is the constant term or the value of Y_i when all the other variables are equal to zero. X_i is a vector of control for individual attributes, K is the kebele fixed effect and ϵ_i is a random error term. α is the coefficient of interest identifying the effect of the interventions on reaching the threshold. The regressions were done on the STATA version 15.1 software package.

Qualitative information and analysis

In order to understand the underlying mechanisms as to how the different communication interventions were influencing farmers' decisions and the role of smartphones as a medium of communication, qualitative data were generated from two sources. Individual interviews were conducted with a total of 27 participant farmers, selecting 3 farmers from each kebele. The interviews were done right after the end of the game in each kebele so that farmers still had fresh memory on their overall experience. The checklist for the interviews was developed in such a way that it encouraged farmers to share their reflections on the different communicative interventions and the way they related the game with their real-life situation as potato growers. The second qualitative data source used to explain the mechanisms behind the quantitative findings was the recording of the phone conversations of the farmers that were given the opportunity to communicate. When farmers came to play between each round of the game, the records were constantly downloaded and the phones cleaned up for the next round of conversation. All the qualitative information from the interviews and the phone records were fully translated and transcribed from the local languages 'Afan Oromo' and 'Amharic'.

The transcribed information from interviews and phone conversations were uploaded on ATLAS.ti software as separate files. Three code categories (*Coordinating collective strategy, Discouraging free-riding behavior* and *Creating a sense of group identity*) were created in line with the reviewed conceptual literature on communicative intervention and collective action in section 2.2. The transcribed information from the two different sources was then openly coded into the three code categories. An inductive analysis of the transcribed information also generated another three themes (*Understanding interdependency, Learn about others' behavior and adjust own decision* and *Implications of using the smartphones*) that mainly investigated farmers' opinion and sense-making of the technical information on interdependency, monitoring information, and (dis-)advantages of using the smartphones as a communication medium.

Results

In a brief descriptive part, section 5.4.1 presents some general information about potato cultivation and late-blight disease in the study sample area. Findings from the quantitative analysis related to our hypotheses are outlined in section 5.4.2. Section 5.4.3 presents a qualitative explanation of how our communication intervention contributed to the observed differences in collective action. The last section (5.4.4) explores some of the contextual implications of using smartphones for communication.

General information about the study population

The livelihood of most farmers in the study area is primarily dependent on the cultivation of potato, cereals such as wheat, barley, and pulses such as faba beans and chickpeas. Some farmers also engage in off-farm activities, mainly as daily laborers in nearby private flower farms and a cement factory to generate additional income. As the study district is located in one of the biggest potato producing areas in the country, potato cultivation is by far the most important source of livelihood for farmers. Table 2 gives a general summary of the relative importance of potato cultivation to farmers' livelihood compared to other income sources in the study area. More than 99% of the respondent farmers labeled potato cultivation as very important or important.

Table 2: Importance of potato cultivation for livelihood.

Rating	Frequency	Percent	Cumulative (%)
Very unimportant	1	0.4	0.4
Unimportant	0	0.0	0.4
Important	20	8.9	9.3
Very important	204	90.7	100.0
Total	**225**	**100.0**	

Farmers' perception of the problem of late blight is another important factor in their efforts in managing the disease. The farmers rated the extent of the problem of late blight to their potato cultivation. The disease was categorized as either a serious or a very serious problem by 80% percent of the farmers and 99% of the respondent farmers labeled it as a problem (Table 3).

Table 3: Importance of late blight as a problem.

Rating	Frequency	Percent	Cumulative
Not a problem	2	0.9	0.9
A mild problem	43	19.1	20.0
A serious problem	63	28.0	48.0
A very serious problem	117	52.0	100.0
Total	**225**	**100.0**	

Variations among the different communicative interventions

The regression outputs on the effect of the different communicative interventions on the level of collective action in the management of late blight are presented here.

Table 4: Communicative interventions and spraying threshold levels as a measure of collective action.

	% of farmers in groups reaching threshold	*P*-value	R-squared
Non-intervention mean	0.44		
Technical information about interdependency	-0.11 (0.0692)	0.125	0.679
Technical information about interdependency + Monitoring information	-0.10 (0.037)*	0.012	0.910
Monitoring information	0.13 (0.040) *	0.002	0.912
Technical information about interdependency + Monitoring information + Group Communication	0.12 (0.039) *	0.003	0.903
Kebele fixed effects	Yes		
Additional controls	Yes		
Observations	225		

Standard errors are reported in parenthesis. * $p < 0.05$. Additional controls include Age, Male dummy, Education level, Household size, Potato farm size, Perceived late-blight seriousness; Mainly seed producer; Mainly ware producer; Mobile phone ownership; Smartphone ownership. See Tables A1-A4 in the Appendix for full details of the control variables and their coefficients.

Hypothesis 1

In the first hypothesis, we predicted that having technical information about interdependency or the collective risk and benefit of individual management practice (fungicide spraying) would have a positive effect on farmers' collective action performance. Contrary to our expectation, the interdependency information did not trigger farmers to collectively act (Table 4). In fact, while about 45% of the farmers were in the non-intervention groups that reached the threshold, with technical information about interdependency only 33% of farmers were in groups reaching the threshold. The difference is not statistically significant.

Hypothesis 2

In the second hypothesis, we expected that additional monitoring information on the decision of other group members (Table 4) would further enhance collective action among farmers. Interestingly, having such information on top of the technical information significantly worsened (p=0.012) collective action performance. Again conflicting with our hypothesis, the additional monitoring information further impeded the performance of the groups; only 34 % of the farmers were in groups that reached the threshold. This is the only intervention group where male farmers performed significantly better than their female counterparts. However, with the small number of female farmers (4 farmers) in the group, a note of caution is to refrain from using this information as evidence of a meaningful positive effect on male farmers than on their female counterparts.

Hypothesis 3

Our assumption was that the role of monitoring information on collective action only is not sufficient to stimulate collective action and farmers need technical information about their interdependency in addition. However, our analysis (Table 3) showed that having only monitoring information had a positive effect on farmers' collective action performance. In this intervention condition 57% of the farmers were in groups that reached the threshold, which is 29% higher relative to the non-intervention condition. This provides evidence that the influence of monitoring information on collective action indeed depends on whether or not farmers have technical information about their interdependency, but not as expected. This finding also signals the uncertainty of using only monitoring information to explain the role of information in altering collective action performance.

Hypothesis 4

Finally, we predicted that allowing people to communicate on top of the technical information about interdependency and monitoring information would produce the highest level of collective action. As can be inferred from Table 4, having the opportunity to communicate has noticeably improved collective action among the farmers in managing the disease. In this intervention condition 56% of the farmers were in groups that reached the threshold. This is a significant ($p=0.003$) increase of 27% relative to the performance of farmers in the non-intervention condition. The increase in performance was even more dramatic when one notices the neutralization of the negative effect of technical information and monitoring information when the opportunity to communicate is given. In this regard, there was a 65% increase in collective action performance relative to the farmers in the intervention group that has both technical information and monitoring information.

How did the communicative intervention influence collective action?

This result section presents detailed qualitative explanations underlying the observed effect of the communicative interventions on collective action. The first two themes (sub-sections 4.3.1 and 4.3.2) mainly relate to the communicative interventions on the provision of technical information and monitoring information. The rest of the themes (sub-sections 4.3.3, 4.3.4 and 4.3.5) cover explanations about the role of group communication in influencing collective action performance.

Understanding interdependency

In contrast with the assumptions, farmers' awareness of their interdependency through technical information has actually encouraged them to pursue an individualistic goal or to free-ride. Farmers' statements on why they would spray their field or advise neighbors to do the same when they saw late-blight symptoms in their own or their neighbors' fields attested this tendency. On his new perspective on interdependency and the 'benefit' that could come with it, a farmer said, *"Today, we saw an interesting thing. We understood the transmission of potato late blight from someone's field to other farmers' fields. For example, if there are 10 hectares of potato field in an area and if 8 hectares got sprayed, the sprayed fields may help in reducing late blight on the fields that never got sprayed".* Another farmer described the dilemma situation they were in, *"There are some individuals in dilemma thinking about the advantage they may get from farmers spraying their potato field near their own field".* Similarly, a farmer shared his opinion on why some farmers in his group did not contribute to the collective management of the disease, *"The reason why some farmers didn't contribute to spraying is that they hoped that if their neighbors would spray, they would benefit from them".*

Contrary to this dominant tendency, the understanding of interdependency stimulated some farmers to be more cooperative or show altruistic behavior. A farmer stated his willingness to even compensate for other farmers, "*I spray for fear of the spread of late blight to my field. Even if the person lacks money for buying a chemical, I have to help him in buying the chemical*". The realization of this type of interdependency influenced another farmer to say, *"So far, I have been doing nothing even if I see late blight on others' fields. But, after this training, I understood the importance of discussing with the other farmers and mobilize them for spraying in order to manage the disease. I also realize even to sue a person if s/he is not willing to spray".*

Learn about others' behavior and adjust own decision

The provision of monitoring information on the decision of other group members after each round of the game appeared to stimulate farmers to adjust their own decision. Knowing about the choices of other farmers without being able to communicate with their group members, the farmers appeared to rely on their individual judgments only and make choices either to compensate for free-riders or to free-ride themselves. As can be seen in the following interview quotes, some farmers covered for free-riders within their groups. *"When I heard others didn't contribute to managing the disease, I decided to provide extra contribution"* was a statement from a farmer. Another frustrated farmer shared his experience, *"I sprayed all the time because others were not, but it is sad we still failed!".* Even though no farmer during the interview dared to say that s/he free-ridded after learning the behaviors of others, our quantitative result has provided evidence that the effect of having additional information on the contribution of others negatively affected collective action performance. This meant that the dominant strategy was to decide to free-ride when farmers learned their group members were not contributing enough.

Coordinating collective strategy

Under the condition of group communication, the farmers discussed their performance after each round of the game and coordinated their collective spraying strategy. They explained their efforts to organize themselves in terms of a collective goal, *"Well, I hear the voicemail and get all the suggestions from the other people and discuss how much is left to reach the target......; "We talked about the amount collected in each round and we made suggestions on the amount that needs to be contributed between rounds".......; "Three of us discussed how to get to the target but we failed as a group because two farmers were not communicating with us".* Correspondingly, farmers being the subject of the other communicative interventions, described how they could have benefited if they had a chance to interact before making decisions. A farmer uttered, "*It would have helped us advise each other about what to do prior to giving decisions to spray or not to spray"*. Another farmer added, *"we would have discussed that we have contributed this amount of money on the first round and advised each other on the amount of money to contribute on the second and third rounds".*

Voice records on the smartphones of the communicating groups provided a strong account of the considerable effort devoted by farmers to calculate and check their collective performance. A farmer emphasized, "*You heard our score and we missed 100 ETB today. Please let's try to compensate for the gap by contributing at least 200 birr"*. Another farmer voiced, *"Today is the last day of the game. We, my group, have contributed around 1000 birr. So contribute the rest and don't try to save the money".* When a farmer realized that they had already met the target before the last round, he prompted, *"We have contributed 1500 birr. So don't contribute hereafter, because contributing more than 1500 is meaningless".*

There was one striking finding that is of relevance in understanding the overall influence of the communicative interventions and particularly on farmers' efforts to coordinate a collective strategy. Despite their understanding of the disease controlling strategy in the game, some farmers tended to apply spraying practices they have in their real-life. Conversation records revealed how these farmers insisted to stick to their actual fungicide spraying routine even when they knew it did not correspond with the optimal strategy in the hypothetical scenario. A farmer asserted, *"As you know, we have an experience of spraying up to four times in our area. According to the trainers, contributing 1500 birr (each spraying three times on average) is enough. But I don't think this is acceptable. Spraying four times is important to get better production. So, each of our group members has to contribute 100 Birr in all the four rounds".* Another farmer voiced his dilemma as, *"The plan for managing potato late blight is contributing 1500 birr or more. But from our experience, we spray a maximum of two times. If we contribute based on this experience, we will fail, what* *should we do?"* In an attempt to guide his group members, a farmer said, *"we know how many times we need to spray to control potato late blight. In this case, spraying one to two times is enough in managing the disease".*

Discouraging free-riding behavior

For the reason explained in the methodology section of this paper, group members were anonymous to each other, consequently, farmers were not in a position to exactly discern between contributors and non-contributors. However, this did not stop farmers from putting pressure on free-riders when they knew that the group was not performing to their expectations. The phone records clearly captured the pressure farmers were trying to exert on cheaters and mobilize other group members to do the same. A farmer denounced the act of an unknown cheater and called for intervention from the others saying*, "We should struggle against the person who did not contribute to spraying".* With what seemed to be categorizing the use of the money for another purpose as a deceitful act, a farmer commented, *"I think there are some individuals who use the money for another purpose".* A farmer who suspected that farmers, who sometimes sent their contributions through other farmers, could be the cheaters, said: *"Those who are sending an empty envelope to another person keeping the money in your pocket have to stop such cheating".*

It is also important to mention that interviewed farmers believed that the social pressure and, consequently, their collective performance could have been different if they had known for sure the free-riding individuals within their groups. *"When I suspected someone is cheating, I only tried to strongly advise everyone"* was a comment from a farmer who could not do more than using a triggering strategy. Another farmer expressed his regrets for not knowing the responsible person for their group failure, *"For example, my group was made of five that later failed to control the disease because we were 100 Birr less than the threshold. We never got to know who was responsible!"*

Creating a sense of group identity

Given the few days (3) the communicating group interacted, it is interesting to see that some forms of group identity emerged. The group communication seemed to initiate a potentially new identity as 'joint late-blight managers', while initially, the farmers saw the disease as an individual problem and the need for collective management more or less was a new concept to them. A farmer stated, *"When we communicate, it motivated us to work cooperatively for our shared goal which is to manage the disease that I now know I cannot do alone".* This new form of identity is also reflected in the following statements when farmers cherished their new 'expert' status and claimed responsibility for educating other members of the community that they believed had a different understanding of the disease and its management. On one of the phone records, a farmer elaborated to his group members "*This chance is given us by God. So what if our group members discuss the potato late blight? Think about it, it is something that may help us and further, we can teach our spouses at home".* A farmer from another group commented, *"We have to teach our society what we learned about the disease here".*

When it came down to the group level, farmers were observed to share ideas on how to behave and act as one district collective. This quick identification of oneself as a member of a particular group is lucid in the voice record, *"Hello my group how are you doing? What are you thinking? What is the status of our group?"* A farmer reminded his group members*, "Put the money in the envelope secretly without any advice from others".* On the other hand, farmers were open to give or take advice from their own group members as an interviewed farmer illustrated, *"Yes, people in my group were consulting about my decision to spray or not to spray by phone. And I told them my decision. They are my group members and since it is for mutual benefit, telling them my own decisions to spray or not to spray has no problem".* Although farmers understood that their group performance was independent of other groups, they still displayed a competitive attitude or wanted to perform better than the others. In the interview, a farmer said, "*We also wanted to be better than other groups, be competitive".* A recorded farmer uttered, *"I have heard that one of the other groups has contributed 400. My group members; please think carefully*".

Implications of using the smartphones

Although the majority of participant farmers had never used smartphones and internet before our experiment, with the brief training most of them were able to operate the smartphone and the application without much difficulty. As a particular type of communication platform, interviewed farmers mentioned some associated advantages and disadvantages that impacted the nature and quality of their communication in their efforts to collectively manage the disease and beyond. The challenges were mainly technical and skill-related on using the touch screen and the Voxer application, and the problem of stable internet connectivity in some of the study sites. Operating the smartphones was particularly difficult for older farmer participants of the experiment. An interviewed farmer commented, "*The phone was difficult to use since we are not very familiar with such type of phone*". "*There was not much problem, but while I was touching, I lost the Voxer on the second day and could not receive and send a message"* was a statement from another farmer. Some of these problems had consequences to their group performance according to a farmer who stated, "*Three of us discussed how to get to the target but two of our group members were not able to communicate with us and because of those two, our group failed to manage the disease"*

Opinions on the advantages, however, focus on the networking or connective features of the platform. Farmers mentioned interesting insights on the advantages of using the smartphones by putting them into perspective with their usual face-to-face communication. Emphasizing the connective power of the platform, a farmer stated, *"It* *would have been difficult to meet up and share the different ideas, but because of the phone it was not tedious for us".* Another farmer added, *"It helped me to discuss with my group members when I was at my work without getting the guys physically. That means we didn't need to contact our group members in person to discuss and share ideas about what to do".*

The connective function of the platform is clearly seen in the phone conversations as farmers used the opportunity to discuss and share experiences on production practices of potato and other crops, and on the importance of getting organized to deal with their market problems. Knowing that his group members are from different villages, a farmer asked, *"If you have any experiences about potato from your area or from other people, let's share with each other".* Another farmer responded, "*Before planting a potato, we have to have our plan including the way and number of tillage and the season of planting. Then after, we have to apply fertilizer during planting and upper dressing. Spraying four times is mandatory"*. On the problem of unfair market and the need to get organized to deal with powerful brokers dictating the market, a farmer commented, "*There is a serious problem in potato marketing. There is no direct selling of potato to the traders so far. We have been selling potato production through brokers which is prohibiting us from getting the right price for the production. It is brokers who are getting more benefits at the expense of farmers".* Another farmer voiced, *"Let us unite and limit the interference of brokers in the market environment".*

If we look into the functional peculiarities of the use of the smartphones as a group communication platform, one interesting encounter relates to the ability of such platforms to influence people to create a virtual identity or exhibit a sort of different character from the way they might behave under other means of communications such as face-to-face. While discussing the perceived advantage of the platform, a farmer said, *"The phone has a great advantage, it helped me talk about anything that is on my mind without any shame. Some farmers were even singing to us".*

Discussion

The role of the communicative interventions

Drawing upon a broader perspective on communicative practices, our study experimented with the role of different types of communicative interventions in the management of potato late blight as a collective action problem. To this end, we examined to what extent and how, 1) technical information about interdependency, 2) monitoring information with and without technical information about interdependency, and 3) interactive communication among farmers influenced their collective action in managing the disease. As highlighted earlier, previous studies on the role of communicative interventions are largely concentrated in behavioral economics and mainly attempted to measure the effect of monitoring information and group communication as distinct areas of research interest (Khadjavi et al., 2017; Opdam et al., 2016; Hashim et al,. 2011; Dietz et al., 2003; Crawford, 1998). Our review also failed to find a study that set out to investigate the role of technical information about interdependency involved in management practices either in combination with other types of communicative interventions or as one typical case. In this regard, it was our assumption that in a context where farmers have very limited information on the collective risk and benefit of individual management practice, the provision of such information would trigger farmers to better cooperate in overcoming their collective problem. Our quantitative results demonstrated that the provision of technical information about interdependency did not improve farmers' collective action performance. The proportion of farmers that were in groups reaching the threshold (manage the disease) was about 25% lower relative to the non-intervention condition even though this negative effect was not statistically significant. Looking into the qualitative information on the way farmers made sense of the technical information as an opportunity to benefit from the spraying of other farmers, having such information could encourage farmers to work against the collective goal of managing the disease.

It was also argued that additional monitoring information on spraying practices of others would further enhance collective action in managing the disease. Our results again revealed that having such additional information even worsen farmers' collective performance whereby the proportion of farmers that were in groups reaching the threshold was significantly lower ($p=0.012$) than the non-intervention condition. Interestingly, farmers who were in groups only given monitoring information performed 29% relatively higher and significantly better than the non-intervention condition. Our hypothesis on the role of monitoring information (*hypothesis 3)* was in view of existing inconsistency in literature on the effect of such type of information and hence, its effect could be influenced by whether or not farmers understand the ecological characteristics of the disease that makes its management a collective action problem. The result supports our hypothesis that the effect of monitoring information could be affected by farmers' understanding of the collective nature of the disease problem and its management. It may be the case that if farmers are only provided with monitoring information, they could use the information to pursue strategies that they think would maximize their income without relating their decisions to their real-life situation or the characteristics of the collective action problem at hand. As is further illustrated in our qualitative analysis, what can be inferred from the effect of both technical and monitoring information, in a situation where awareness of interdependency (technical information) promotes free-riding behavior, knowing the less satisfactory collective performance (monitoring information) could further encourage farmers to free-ride. When farmers that were in groups with both technical information and monitoring information were given a chance to interactively communicate, they performed significantly better (27%) than the farmer groups in the non-intervention condition and about 65% higher than farmers that were in the groups with both technical information and monitoring information.

Against this background, our finding on the role of technical information about interdependency by no means leads to a conclusion that the provision of this type of information is detrimental to collective action in the management of the disease. Neither does the positive effect of monitoring information lead to the suggestion that monitoring of management decisions alone would be a solution to overcome collective action problems. Rather, as demonstrated in the communicating group, it underscores the importance of a combination of communicative interventions that go beyond just providing information and creates room for farmers to interact, learn and coordinate their actions towards a collective goal. As highlighted by Leeuwis and Aarts (2011), beyond the provision of relevant information, meaningful change depends on creating a space for human interaction and negotiation, and its formation is inherently dependent on an interactive form of communication.

Mechanisms in interactive communication

Previous studies on collective action problems have hypothesized or used qualitative case studies to explain the mechanisms under which interactive communication could influence collective action (Garicano and Wu, 2012; Cardenas et al., 2004; Dietz et al., 2003; Ostrom and Walker, 1991). Apart from employing such conceptual perspectives to substantiate the role of group communication, our study additionally attempted to integrate and inductively investigate how the provision of both technical and monitoring information influenced collective action performance as reported in the quantitative findings. Through the analysis of interviews and phone conversations, the study provided explanations on the way farmers made sense of the information types to inform their individual decisions. Interesting accounts were captured that explained some of the underlying motives to pursue individual goals rather than a collective one or vice versa. A new appreciation of interdependency that stems from the collective nature of managing the disease, and the chance to inform their decisions based on the decision of others had a meaningful impact in shaping their cooperative behaviors. This brings a fresh perspective to existing literature that so far attempted to explain the role of information only from the perspective of monitoring information or how knowledge on the propensity of others' to cooperate influences collective action (Fischbacher and Gachter, 2010; Croson and Jen, 2008; Croson, 2007). Farmers in the communicating groups used the opportunity to coordinate a collective strategy, to put pressure on free-riders and to create a sense of group identity that explains the positive effect of the group communication on collective action performance. Because of the experimental design choice of our study, farmers in a group were anonymous and from the different statements of farmers, the anonymity seemed to negatively influence the role of the group communication especially in their attempt to discourage free-riding behavior. Even so, they tried to use the opportunity to arouse what Ostrom and Walker (1991) called 'internal guilt' on individuals who were believed to have shown non-conforming behaviors. However, our study would not fall short of recognizing the premise that the type of social pressure in collective action problem situation is not only about individuals' perception of the wishes and norms of others but also involves dynamics of power and enforcement whereby the detection of individual behaviors becomes important (Cubitt et al., 2011; Ostrom, 1990). In general, having a good understanding of the underlying mechanisms would help in the development of an empirically validated theory that explains why communicative interventions would be (in)efficient in the management of collective action problems in a given situation. From a practical viewpoint, this also provides an opportunity to improve or adapt communicative intervention approaches around the management of collective action problems. For instance, the fact that some farmers tried to negatively influence other farmers by bringing their real-life spraying practice is one such contextual case that a communicative intervention could take into account to optimize its contextual relevance.

Trade-offs associated with smartphone use

Finally, our study also assessed the potential trade-offs of using smartphones as a medium of option for group communication. Our aim to look into the smartphone as a communication tool in a wider communicative intervention was rationalized by the fact that the mechanisms underlying the role of the group communication (e.g. coordinating collective strategy, pressuring free-riding behavior or creating a sense of group identity) are considered to be consequences of the opportunity to communicate in general. However, it was in the interest of this study to unravel the potential trade-offs that could come along with the use of a particular type of communication platform. From this end, most of the disadvantages of using the smartphones were related to skills on the proper use of the smartphone, and the problem of reliable internet connectivity. As much as physical infrastructural and knowledge gaps in the use of ICTs are common constraints mentioned in many studies, it is also becoming less and less persistent due to the growing investment and rapid ICT expansion in rural Africa (Asongu et al., 2018; Maumbe and Okello, 2013; Adam, 2012). Despite some challenges expressed by few interviewed farmers, our quantitative results also corroborated that previous exposure or being an owner of a mobile phone or a smartphone was not a significant factor to influence collective action in both the intervention and non-intervention groups. In contrast, an important advantage of using the smartphone relates to its connective power that allowed farmers to discuss their strategies when they were physically distant to each other. The ability of ICT to overcome geographic barriers has already been an established notion with the potential of facilitating new forms of collective action or what Bennet and Segerberg (2012) call 'connective action'. Likewise, the use of smartphones has also signaled a prospect for catalyzing wider connectivity beyond the community as farmers discussed other issues such as market problems and the idea of getting organized to deal with powerful market actors. However, this also demonstrates that such new forms of ICT-induced connectivity can also be utilized to push other agendas that were not intended by a communicative intervention.

Although it was not raised by many farmers, the idea that the virtual platform encouraged people to speak their minds which they could hesitate to do in face-to-face communication evoked the notion of 'digital dualism'. Jurgensen (2011) highlighted that a separate digital and physical sphere affects the way people behave that could potentially create a 'second self'. We believe that this could pique interest in future research on understanding the diverse implications of ICT-enabled communicative interventions in the management of collective action problems.

External validity

Even though the anonymity among farmers ensured internal validity by minimizing a potential bias that could have come from farmers' interaction in the non-communicating groups if they had known each other, the conditions of the experiments do not reflect the real-life of farmers. In reality, it is less likely or not commonly the case that farmers in a community do not know each other. In this regard, our case study was not free from the enduring epistemic dilemma of choosing from or balancing between internal and external validity. In addition, for simplifying the game for farmers and logistical reasons, the design took (not) spraying as the only important factor in late blight occurrence, while in reality other abiotic factors (e.g. temperature, humidity, rainfall) play role in the likelihood of disease occurrence. Future research can capitalize on this by including, for instance, uncertainty element or multiple scenarios to levels of disease occurrence under different environmental conditions. Finally, in the experiment, the farmers did not have to invest their own money in disease management or group communication. The latter was paid for (internet and mobile data) with an average of 25 ETB or 0.85 Euro cents per farmer. As Ostrom (2012) noted, irrespective of the means of communication, it is rare that the opportunity to communicate is costless as someone has to invest money, time or effort to create and maintain arenas for communication. Likewise, the research project provided the initial spraying investment of 400 ETB (13.60 Euro) per farmer. When designing communicative interventions in collective action problem situations it is hence important to take into account the sources for the costs of creating a communication space and a common good provision investment.

Conclusion

Dealing with collective action problems such as the management of late blight requires more than technical information provision or about interdependencies involved in management practices of farmers. In fact, communication practices that are mainly geared towards increasing farmers' awareness of such technical facts could negatively affect collective action. Furthermore, providing monitoring information about the practices of others when there is already a weak collective action could further promote non-cooperation in the management of the disease. In light of this, expert advisory services and/or provision of relevant technical and social information have to be complemented with interactive communication and deliberation processes that are internally governed or managed by communities. This would help in making the best out of advisory services and monitoring practices that could otherwise be counterproductive.

From an analytical viewpoint, apart from showing the direction or magnitude of relationships between communicative interventions and collective action performance, employing conceptual perspectives that shed light on what really happened during communicative interventions is an important step in understanding how different types of communicative practices facilitate or obstruct collective action in a particular context.

The use of smartphones has demonstrated the potential for such platforms in facilitating networking and connectivity among specially and temporally scattered community members. However, farmers' attempt to use the platform for advancing other agendas would mean that communicative research and/or development interventions need to take into consideration any unintended consequences of using such platforms and how these interplay with the envisioned objective of a communicative intervention in the management of collective action problems.

References

Adam, L., 2012. Understanding what is happening in ICT in Ethiopia: A supply and demand-side analysis of the ICT sector, Evidence for ICT Policy, Action Policy Paper 3. https://researchictafrica.net/ Accessed 22 Novermber 2019.

Adekunle, O.O., 2013. The Use of the Instrumental and Interactive Approaches of Communicative Intervention in the Control of Foot and Mouth Disease in the Eastern Cape. *Journal of Agricultural Science*, *5*(12), 87.

Andreoni, J. and Ragan P., 2004. Public goods experiments without confidentiality: a glimpse into fund-raising. *Journal of Public Economics*, *88*(7-8), 1605-1623.

Asongu, S., and Agyenim B., 2018. Introduction to special issue: Mobile technologies and inclusive development in Africa. *Journal of African Business*, 19(3), 297– 301

Bachi, B., Sambuddha G, and Zvika N., 2010. Prisoner's dilemma with talk. http://www.dklevine.com/lectures/evolution/bachi.pdf Accessed 22 November 2019.

Balliet, D., 2010. Communication and cooperation in social dilemmas: A meta-analytic review. *Journal of Conflict Resolution*, *54*(1), 39-57.

Bell, A. Wei Zhang, and Keosothea N., 2016. Pesticide use and cooperative management of natural enemy habitat in a framed field experiment. *Agricultural Systems,* 143, 1-13.

Bennett, W. L, and Alexandra S., 2012. The logic of connective action: Digital media and the personalization of contentious politics. *Information, Communication & Society*, *15*(5), 739-768.

Bochet, O, Talbot P, and Louis P., 2006. Communication and punishment in voluntary contribution experiments. *Journal of Economic Behavior & Organization*, *60*(1), 11-26.

Burke, John J. 2017. Growing the Potato Crop. Dublin 7, Ireland: Vita, Equity House, Upper Ormond Quay.

Cabrales, A., Feri, F., Gottardi, P and Meléndez-Jiménez, M., 2016. Can There Be a Market for Cheap-Talk Information? Some Experimental Evidence. CEPR Discussion Paper No. DP11206. https://ssrn.com/abstract=2766534. Accessed 25 July 2019.

Campos, H, and Ortiz, O., 2019. The Potato Crop: Its Agricultural, Nutritional and Social Contribution to Humankind. Switzerland: Springer Nature.

Cárdenas, Juan-Camilo, and E Ostrom, E., 2004. What do people bring into the game? Experiments in the field about cooperation in the commons. *Agricultural systems*, *82*(3), 307-326.

Cardenas, Juan-Camilo, T. K. Ahn, and Ostrom. E., 2004. Communication and co-operation in a common-pool resource dilemma: A field experiment. In: Advances in Understanding Strategic Behaviour (pp. 258-286). London: Palgrave Macmillan.

Cason, Timothy N., Roman M. Sheremeta, and Jingjing Z., 2012. Communication and efficiency in competitive coordination games. *Games and Economic Behavior*, *76*(1), 26-43.

Ciancio, Aurelio, and K. G. Mukerji. 2008. Integrated Managment of Diseases Caused by Fungi, Phytoplasma and Bacteria, Vol. 3. Springer. The Netherlands.

Cieslik, K. J., Leeuwis, C., Dewulf, A. R. P. J., Lie, R., Werners, S. E., Van Wessel, M., P. Feindt, and Struik, P. C. 2018. Addressing socio-ecological development challenges in the digital age: Exploring the potential of Environmental Virtual Observatories for Connective Action (EVOCA). *NJAS-Wageningen Journal of Life Sciences*, *86*, 2-11.

Choi, S., and Jihong L., 2014. Communication, coordination, and networks. *Journal of the European Economic Association*, *12(1)*, 223-247.

Costello, C., Nicolas Q., and Agnes T., 2017. Private eradication of mobile public bads. European Economic Review *94 (2017)*, 23-44.

Crawford, V., 1998. A survey of experiments on communication via cheap talk. *Journal of Economic Theory*, *78(2)*, 286-298.

Croson, R., 2007. Theories of Commitment, Altruism and Reciprocity: Evidence from Linear Public Goods Games. *Economic Inquiry, 45(2)*, 199–216.

Croson, R, and Jen S., 2008. The Impact of Downward Social Information on Contribution Decisions. *Experimental Economics*, 11(3), 221–33.

Cubitt, Robin P., Michalis D., Simon G., and Ruslan K., 2011. Moral judgments in social dilemmas: How bad is free riding? *Journal of Public Economics 95*, 3(4), 253-264.

Damtew, E., Barbara van Mierlo, B., Lie, R., Struik P.C., Cees Leeuwis, C., Lemaga, B and Smart. C., 2020. Governing a Collective Bad: Social Learning in the Management of Crop Diseases. *Systemic Practice and Action Research, 33(1)*, 111-134.

Damtew, E., Tafesse, S., Rico Lie, Van Mierlo, B., Lemaga, B., Sharma, K., Struik, P.C. and Leeuwis. C., 2018. Diagnosis of management of bacterial wilt and late blight in potato in Ethiopia: A systems thinking perspective. *NJAS-Wageningen Journal of Life Sciences, 86*, 12-24.

Demissie, Y. T., 2019. Integrated Potato (Solanum Tuberosum L.) Late Blight (Phytophthora Infestans) Disease Management in Ethiopia. *American Journal of BioScience, 7(6)*, 123-130.

D'Exelle, B., Els L., and Bjorn V. C., 2012. Equity-efficiency trade-offs in irrigation water sharing: evidence from a field lab in rural Tanzania. *World Development 40 (12)*, 2537-2551.

Dietz, T., Ostrom, E., and Paul C. S., 2003. The struggle to govern the commons. *Science, 302(5652)*, 1907-1912.

Fischbacher, U. and Simon G., 2010. Social preferences, beliefs, and the dynamics of free riding in public goods experiments. *American Economic Review, 100(1)*, 541-56.

Franc, G. D., 1998. An Introduction to Plant Pathology and Plant Disease Management. University of Wyoming, Cooperative Extension Service.

Garicano, L., and Yanhui Wu. 2012. Knowledge, communication, and organizational capabilities. *Organization Science, 23(5)*, 1382–1397.

Graham, S., Alexander L. Metcalf, N.G, Rebecca N., Carlo M., Thomas B., Victoria I., Lars H., Zhao Ma, and Alice L., (2019). Opportunities for better use of collective action theory in research and governance for invasive species management. *Conservation Biology 33(2)*, 275-287.

Hashim, Matthew J., Karthik N. Kannan, and Sandra Maximiano. 2017. Information feedback, targeting, and coordination: An experimental study. *Information Systems Research, 28(2)*, 289-308.

Janssen, Marco A., Robert Holahan, Allen Lee, and Elinor Ostrom 2010. Lab experiments for the study of social-ecological systems. *Science, 328(5978)*, 613-617.

Jurgensen, N. (2011) Digital Dualism and the Fallacy of Web Objectivity. Cyborgology. http://thesocietypages.org/cyborgology/2011/09/13/digital-dualism-and-the-fallacy-of-web-objectivity/.Accessed November 2019.

Khadjavi, M., Andreas L., and A. N., 2017. How transparency may corrupt– experimental evidence from asymmetric public goods games. *Journal of Economic Behavior & Organization, 142*, 468-481.

Kirk, William W., and Phillip S. Wharton. 2014. Fungal and bacterial disease aspects of potato production. In: Navarre, R. and Pavek, M. (Eds.), The Potato, Botany, Production and Uses. Chapter 11, CABI, Boston, MA., pp: 167-201.

Klerkx, L., and Leeuwis C.,. 2008. Matching demand and supply in the agricultural knowledge infrastructure: Experiences with innovation intermediaries. *Food Policy 33 (3)*, 260-276.

Klerkx, L., Hall, A. and Leeuwis, C., 2009. Strengthening agricultural innovation capacity: are innovation brokers the answer? *International Journal of Agricultural Resources, Governance and Ecology, 8(5-6)*, 409-438.

Leeuwis, C., 2004. Communication for Rural Innovation. Rethinking Agricultural Extension, 3rd ed. Blackwell Science, Oxford.

Leeuwis, C., 2010. Changing views of agricultural innovation: Implications for communicative intervention and science. In Research to Impact: Case Studies for Natural Resource Management for Irrigated Rice in Asia; International Rice Research Institute: Manila, Phillipines: pp. 15–32.

Leeuwis, C., and Aarts. M. N. C. 2011. Rethinking communication in innovation processes: creating space for change in complex systems. *Journal of Agricultural Education and Extension, 17(1)*, 21-36.

Leeuwis, C., and M. N. C. Aarts. 2016. Communication as intermediation for socio-technical innovation. *JCOM Journal of Science Communication, 15(6)*.

Marks, M. B., and Rachel T.A. Croson. 1999. The effect of incomplete information in a threshold public goods experiment. *Public Choice, 99(1-2)*, 103-118.

Martin, J. M., Cleotilde G., Ion J., and Christian L., 2014. A description–experience gap in social interactions: Information about interdependence and its effects on cooperation. *Journal of Behavioral Decision Making, 27(4)*, 349-362.

Maumbe, Blessing M., and Julius J. O., 2013. Uses of information and communication technology (ICT) in agriculture and rural development in sub-Saharan Africa: Experiences from South Africa and Kenya. In: Technology, Sustainability, and Rural Development in Africa (pp. 113-134). IGI Global.

Milinski, M., Sommerfeld, R.D., Krambeck, H.J., Reed, F.A. and Marotzke, J., 2008. The collective-risk social dilemma and the prevention of simulated dangerous climate change. *Proceedings of the National Academy of Sciences, 105(7)*, 2291-2294.

Miller, Jeffrey S., Phil N., Nora O., Terry M., Bill B., and Mike T., 2006. Late blight management action plan for potatoes. University of Idaho Extension.

Olson, M., 2009. The logic of collective action. Vol. 124. Harvard University Press, Cambridge.

Sell, Jane, and Rick K. Wilson. 1991. Levels of information and contributions to public goods. *Social Forces, 70(1)*, 107-124.

Opdam, Paul, Ingrid Coninx, Art Dewulf, Eveliene Steingröver, Claire Vos, and Merel van der Wal. 2016. Does information on landscape benefits influence collective action in landscape governance? *Current Opinion in Environmental Sustainability, 18*, 107-114.

Ostrom, E., 1990. Governing the commons – the evolution of institutions for collective action. Cambridge University Press, New York.

Ostrom, E., 1992. Crafting institutions for self-governing irrigation systems. Institute for Contemporary Studies, San Francisco, California, USA.

Ostrom, E., 1999. Design principles and threats to sustainable organizations that manage commons." In Paper for electronic conference on Small Farmer's Economic Organizations, organized by Julio A. Berdegue. Santiago, Chile.

Ostrom, E., 2012. Experiments Combining Communication with Punishment Options Demonstrate how Individuals can Overcome Social Dilemmas. *Behavioral and Brain Sciences, 35(1)*, 33-34.

Ostrom, Elinor, E., and Walker J.,. 1991. Communication in a commons: cooperation without external enforcement. Laboratory research in political economy, 287-322.

Pande, A., Bhushan G. Jagyasi, and Ravidutta C., 2009. Late blight forecast using mobile phone-based agro advisory system. In International Conference on Pattern Recognition and Machine Intelligence (pp. 609-614). Springer, Berlin, Heidelberg.

Peng, X., George Hendrikse, and Wendong D., 2018. Communication and innovation in cooperatives. *Journal of the Knowledge Economy, 9(4)*, 1184-1209.

Pernezny, K., Elliott, M., Palmateer, A., and Havranek. N., 2016. Guidelines for Identification and Management of Plant Disease Problems: Part II. Diagnosing Plant Diseases Caused by Fungi, Bacteria and Viruses. Plant Pathology Department, UF/IFAS Extension publication.

Petty, Richard E., and John T. Cacioppo. 1986. The elaboration likelihood model of persuasion. In Communication and persuasion, pp. 1-24. Springer, New York.

Reuben, E., and Riedl. A., 2013. Enforcement of contribution norms in public good games with heterogeneous populations. *Games and Economic Behavior, 77(1)*, 122-137.

Rogers Everett, M. 1995. Diffusion of innovations." Free Press, New York.

Smith, E. A., 2010. Communication and collective action: language and the evolution of human cooperation. *Evolution and Human Behavior, 31(4)*, 231-245.

Steingröver, Eveliene G., Willemien Geertsema, and Walter K. R. E. van Wingerden. 2010. Designing agricultural landscapes for natural pest control: a transdisciplinary approach in the Hoeksche Waard (The Netherlands). *Landscape Ecology, 25(6)*, 825-838.

Tafesse, S., Damtew, E., Van Mierlo, B., Lie, R., Lemaga, B., Sharma, K., Leeuwis, C., and C. Struik. P.C., 2018. Farmers' knowledge and practices of potato disease management in Ethiopia. *NJAS-Wageningen Journal of Life Sciences, 86*, 25-38.

Tsedaley, B., 2014. Late blight of potato (Phytophthora infestans) biology, economic importance and its management approaches. *Journal of Biology, Agriculture and Healthcare 4(25)*, 215-225.

Weimann, J., 1994. Individual behavior in a free-riding experiment. *Journal of Public Economics 54(2)*, 185-200.

6

Chapter 6

Synthesis

Introduction

This thesis has approached the problem of the management of crop diseases, such as potato late blight and bacterial wilt, as a collective action problem whose governance requires change in the technical and socio-institutional sphere. The study aimed, first, to understand and redefine the problem of late blight and bacterial wilt management in Ethiopia with a social-technical lens. The problem situation was analyzed within the broader crop disease management system that affects practices specific to both diseases. Informed by such a scoping phase, it then advanced to investigating the role that different social-technical interventions can play in the collective management of crop diseases in general and late blight in particular. Late blight was used as a case to generate insights specific to collective management of late blight and for crop disease management in general. With this objective in mind, the study diagnosed the problem situation, and designed and implemented different types of learning and communication interventions to answer the following four research questions:

1. How do actors' view the technical and social-institutional problem features of late blight and bacterial wilt and with what implication to the management of the diseases?

2. What is the role of farmers' knowledge and associated practices in the management of the diseases?

3. How does social learning contribute to farmers' collective action in the management of late blight?

4. How and to what extent do different types of communicative intervention influence farmers' collective action in the management of late blight?

The next section of the synthesis chapter (Section 6.1) summarizes the key findings of the four research questions. Section 6.2 discusses overarching themes that are considered central topics and that synthesize major insights from the different chapters of the thesis. In Section 6.3, implications for development and policy action are discussed based on the findings of this thesis and the researcher's personal observations. The final section (Section 6.4) suggests ideas for future research.

Major findings

How do actors' view the technical and social-institutional problem features of late blight and bacterial wilt and with what implication to the management of the diseases?

The central premise of *Chapter 2* is that the management of late blight and bacterial wilt is a complex problem with multiple technical and socio-institutional problem dimensions. Addressing such a type of problem requires actors to appreciate their interdependency and, hence, enhance their coordinative capacity. From this perspective, the chapter set out to explore the key technical and social-institutional problem features of the management of late blight and bacterial wilt. The study employed a soft systems perspective whereby actors' understanding of the problem and their responses to the problem were used to explain the problem situation. The chapter also assessed the potential for community-based and preventive disease management interventions within which opportunities for ICTs or digital platforms are explored. Multiple technical and institutional problem dimensions (*Disease diagnosis and risk monitoring, Disease management strategy, Seed quality control, Research and extension, Politics and power relations* and *Information sharing culture*) were used as entry points to examine actors' understandings, perceptions and practices on the problems of late blight and bacterial wilt and its management.

Chapter 2 provided interesting insights into the informal and less tangible social and institutional problem aspects that played a crucial role in shaping practices in the management of crop diseases in general and that of late blight and bacterial wilt in particular. Lack of a preventive management culture, limited recognition of interdependencies between activities of actors, power inequalities, and top-down and linear approaches in information and knowledge sharing are among the key systemic problems identified. Consequently, management responses mainly involve uncoordinated short-term reactions in which potato late blight and bacterial wilt received very limited attention compared to other crop and pest disease problems in the country.

Chapter 2 proposed that a bottom-up and participatory disease management strategy that can facilitate learning, collaboration and collective action may serve as a tipping point or 'local' solution to wider systemic problems. A community-based management strategy may drive positive change to the problem of late blight and bacterial wilt. Within this framework, ICTs and digital platforms were indicated to have a possibility to structurally alter the existing top-down flow of information and power inequalities by decentralizing information flow, decreasing dependency and providing a framework for shared learning.

What is the role of farmers' knowledge and associated practices in the management of the diseases?

Chapter 3 added to the understanding of the problem situation by further exploring knowledge and associated practices of farmers as a way of identifying promising entry points for learning processes that facilitate either collective management of the diseases or a community-based management strategy. The chapter generated evidence on how farmers' practices, informed by their knowledge, contributed to the spreading of the diseases rather than managing it. Existing extension services that enact conventional methods of training and instructional approaches were not effective in stimulating learning, especially around specific types of knowledge (know-how and know-who of the diseases and their management) which require social interaction and practical engagement for learning.

Chapter 3 underlined that farmers need to learn about different aspects of the diseases, including causes, symptoms, spreading mechanisms, and how to integrate effective management methods into their daily practice. Such learning is suggested in helping enhance farmers' awareness about their interdependency and, hence, emphasize the need for collective action. To collectively act, it was highlighted that institutional arrangements were needed whereby farmers can mutually agree on different social practices and operational procedures through bylaws, monitoring systems, incentives, and sanctioning mechanisms. The chapter indicated that enabling, enforcing and evaluating collective action in the management of the diseases requires learning processes that, on the one hand, aim to enhance technical knowledge and practices to manage the diseases and, on the other hand, help forge the required institutional mechanisms. Reflecting on the possible roles of digital platforms, especially mobile phones, the study suggested that such platforms could play an institutional (e.g. peer-to-peer monitoring of agreed practices) and technical function (e.g. early warning/decision support systems or information provision on appropriate disease diagnosis or management practices).

How does social learning contribute to farmers' collective action in the management of late blight?

Chapter 4 explored the role of social learning in overcoming collective action problems in the management of late blight and crop disease management in general. The central argument of *Chapter 4* reflects the findings of *Chapter 3,* namely that simultaneous learning is needed to stimulate collective action among farmers. Such learning enhances technical knowledge about crop diseases and their management, and facilitates the re-ordering of social relationships and institutional arrangements needed to act collectively. Taking late blight as a case, social learning is studied as a communicative process that aligns new knowledge, relations and suggested actions to form the basis of collective action in the management of the disease. Collective action was approached both at the level of agreements and the actual implementation of the agreements. The study presented a number of communicative utterances that aligned new knowledge, relations and suggested action (agreements) and the link between the agreements and actual collective action.

The study showed that new knowledge about the less visible life cycle and the spreading nature of the late blight pathogen plays a key role in stimulating discussions about relations and actions that ended with agreements on nine different practices for implementation by farmers. Farmers were able to reach agreements on different social-technical practices such as team field scouting for late blight detection, monitoring individual management practices and sanctioning non-compliance. Conversely, new insights into important ecological characteristics of late blight was not a sufficient reason for some farmers to develop interest in engaging in collective practices. Depending on resource conditions or the amount of investment that a farmer is able/willing to dispense for management practices (e.g. fungicide spraying or labor), the management of late blight can still be considered by farmers as a private problem that does not necessarily require them to engage in collective practices.

Chapter 4 also demonstrated that social learning can facilitate the emergence of a rudimentary type of institutionalized coercion and new types of reciprocity, such as helping fellow farmers in disease monitoring and peer-to-peer financial support to buy fungicide. Institutional arrangements in the form of monitoring systems and sanctioning mechanisms were found to best stimulate collective action if they emerge and evolve within communities rather than being pushed externally. The chapter also documented how most of the collective agreements were implemented on the ground and how some agreements could not be translated into actual collective action. It was concluded that social learning is a necessary condition for collective action but not always leads to it as several other factors (e.g. individual farmers' risk perception, production objective, institutional and/or geographic boundary of the problem, etc.) can interplay between agreements and actual (collective) action.

How and to what extent do different types of communicative intervention influence farmers' collective action in the management of potato late blight?

Chapter 5 questioned the role of different types and combinations of communicative intervention in overcoming farmers' collective action problems in the management of late blight. Under different combinations, three types of communicative intervention were studied: 1) provision of *technical information* about interdependency from the risks and benefits of individual late blight management practice, 2) provision of *monitoring information* about the management practice (spraying) of other farmers, and 3) opportunities for *interactive communication* among farmers. *Chapter 5* also empirically assessed the potential trade-offs associated with the use of smartphones as a medium of communication in one of the communicative interventions (*interactive communication*).

The findings showed that the provision of *technical information* did not improve collective action performance among farmers. This is contrary to the initial assumption in the chapter that farmers would cooperate better if they knew that their success in controlling the disease depends not only on their individual action but also on the actions of other farmers. Linked with the initial assumption, the study also predicted that providing additional *monitoring information* would further improve collective action. However, the *monitoring information* was provided in a situation where awareness of interdependency (*technical information*) was promoting free-riding behavior and this was found to exacerbate collective action performance. The study also showed the positive effect of *monitoring information* on collective action when provided alone. This situational role of monitoring information indicated how its effect could depend on whether or not farmers have technical information about their interdependency given the contagious nature of the disease. Opportunities to interactively communicate after farmers were provided with *technical information* and *monitoring information* wwere found to significantly improve collective action.

The chapter provides further insights into how the different types of communicative intervention influenced collective action behaviors. The communicative interventions helped farmers to appreciate their interdependency, to learn about each other's behavior and adjust their own action, to coordinate a collective strategy, to discourage free-riding and to create a sense of group identity. Despite problems with the ICT infrastructure and skill-related challenges, the smartphone enabled broader connectivity among farmers. The smartphone allowed them to discuss their strategies and influence decisions, even when they were physically distant from each other. *Chapter 5* concludes that the provision of relevant technical and social information, for instance in the form of expert advisory services (conventional extension), could impede collective action unless it is complemented with interventions that create a space for an interactive type of communication and for deliberation processes.

Discussion on overarching themes

Collective action problem features of crop disease management

The thesis examined the problem of management of crop diseases such as late blight as a collective action problem upon which the role of different learning and communicative interventions in overcoming the problem was further justified and studied. However, the lack of a strong social science perspective on the collective nature of the problem and on the management of such a collective problem represents a major gap in the literature. Hence, a key motivation for this thesis was to broaden the understanding of the problem, and to investigate the types of technical and social-institutional re-ordering needed in the management of crop diseases such as late blight. A number of interesting insights were proffered in the different chapters of the thesis about the collective action problem features of late blight that have important general implications for other contagious crop diseases.

Problem boundary and the difficulty of defining a 'community'

The collective action approach to the management of late blight was primarily based on the spreading nature of the pathogen and farmers' interdependency in managing it. It has been emphasized that the late blight pathogen is airborne and that it is a problem that goes beyond an individual farm or farmer (Burke, 2017; Miller et al. 2006). Although it is to a lesser degree, late blight pathogen is also a seed-borne (Arora et al., 2014) that can travel a much longer distance in the seed system. The movement of the pathogen in the seed system brings a different and wider boundary to the problem as it involves farmers that can be hundreds of kilometers away from each other but are interacting through seed marketing. If one looks into the propensity of late blight pathogen to transverse farm boundaries in the air, the boundary is smaller and disease management approaches need to deal with geographically closer communities. But when a crop disease is also seed-borne, the problem boundary becomes larger and management approaches will need to involve geographically dispersed communities that sell, buy or exchange seed potato.

Chapter 4 also revealed institutional interdependencies among farmers in managing the disease, such as through land contract farming that gives different responsibilities for disease management practices. This issue has also been highlighted by another study whereby such institutional type of interdependence among farmers was problematic to delineate a boundary on who needs to be included or not included in a disease monitoring system (Shiferaw, et al., 2020). This appears to give the problem of late blight, and contagious crop diseases in general, a fussier boundary than other collective problems involving relatively geographically defined communities (Cox et al. 2010; Ostrom, 2010). For instance, the management of many common-pool resources mainly involves people that are in a relatively distinct geographic area and are found close to a resource (Baggio et al. 2016; Ostrom, 2010).

Such ecological and institutional problem features of late blight have implications for the type and nature of the disease management strategy. For instance, it was suggested in the diagnostic chapters of the thesis (Chapters 2 and 3) that a community-based management approach would be a promising intervention for the management of both late blight and bacterial wilt. While this study still strongly advocates for a collective, community-driven disease management strategy that embraces change in technical and social practices, it also identifies the difficulty of defining what constitutes a 'community' or 'community-based' management when the problem has a fuzzy boundary. Farmers from geographically distant areas can still have interdependency relevant for the management of a disease. As a result, what constitutes a 'community' in the context of crop disease management such as late blight is not only defined by interdependence due to the spreading nature of the pathogen but also interdependence in socio-institutional practices that have consequences for crop disease management.

6

The extent of interdependence is dependent on resources

Another feature to the management of late blight as a collective action problem relates to the type of farming system and the resource conditions of farmers in a particular context. The degree of 'collectiveness' of managing late blight is higher for farmers that are in a poor resource condition. *Chapter 4* determined that most well-to-do farmers did not see the need to work with others as they believed that they could control the disease with spraying as required. This clearly indicates that the level of farmers' interdependence in managing the disease can be affected by farming systems and resource conditions. This is consistent with the premise that public good features of a disease management strategy depend on specific agro-ecological features of the disease, the available technological options, and community-specific social conditions and resources (Leeuwis et al., 2018).

The importance of awareness of the 'collective' nature of the problem

An important aspect of approaching crop disease such as late blight as a collective problem and, hence, in the design of management strategies is farmers' understanding or perception about the 'collective' nature of the problem. The thesis thus highlighted the existing inattention in the literature to the vital question of whether communities or resource providers are aware of their interdependence from the perspective of disease management. The existing inattention appears to presuppose that people understand that they have a collective problem and the dilemma of conflicting individual versus collective goals. In this thesis, it is clearly shown that this is not always the case, especially not for crop diseases that are characterized by less visible pathogens, hosts, environment and human interactions. As can be observed from the discussion in the next sections, this understanding shaped the perspective underpinning the design of the interventions studied in *Chapters 4 and 5*.

Social learning approaches in crop disease management

The critique in this thesis on the implicit assumption in the literature that people recognize their collective problem and appreciate their interdependence in managing it has important implications to the social learning approach employed in the study. This sub-section reflects on the methodological and analytical approaches to social learning, relevant for the management of late blight and crop disease in general.

Facilitated versus self-organized learning

Social learning can take place as a result of guided processes in which external intervention mainly takes the form of facilitation. It can also result from self-organized processes among people interacting in different platforms and settings (Koontz, 2014; Leeuwis and Pyburn, 2002). In this case, the fact that farmers do not see the need to collectively act meant that an externally facilitated learning intervention was necessary at the initial stage to help highlight interdependency. However, as was demonstrated in *Chapter 4*, some learning processes and evidence of social learning occurred without external facilitation, such as self-initiated, gradual inclusion of more farmers and the re-consideration of a sanctioning system after it was initially dismissed when suggested by a learning facilitator. This demonstrates that externally facilitated social learning interventions can still be relevant in contexts where communities do not themselves see the need to coordinate their efforts. However, even in such contexts, a learning intervention has to balance between bringing the need to work together to the community's attention and creating ample space and modality for self-initiated, emergent processes of social learning.

Analyzing processes of social learning

A useful addition to the discourse on social learning related to crop diseases management is the conceptualization and analysis of social learning as an emergent, adaptive and iterative process of knowledge co-production, changing relations and actions. Tracking such processes was shown to be an important undertaking in order to understand how and why certain learning processes led to change in practices or collective action while others did not. In this context, the thesis also demonstrated that the analysis of verbal communications or discursive interactions of people is a powerful way of analyzing social learning processes. As also noted by Gee and Green (2014), verbal communication remains the most common way of producing and transmitting meaning in society.

The role of communicative interventions and complementarity with social learning

The social learning study (Chapter 4) and the study on communicative interventions (Chapter 5) were informed by perspectives rooted in different disciplines and fields of research. However, both studies aimed to understand the role of two different but complementary types of intervention in addressing a similar collective action problem situation. In this regard, some important complementarities are drawn from the different conceptual lenses and the findings in *Chapters 4* and *5*.

Technical information about interdependence

Although the literature on communicative practices provided useful insights into the role of social information and peer-to-peer monitoring in overcoming collective action problems (see Chapters 1 and 5), it rarely focused on the importance of technical information on interdependencies from the biophysical features of crop diseases. The fact that farmers essentially perceived late blight as an individual problem, needing an individual solution, highlighted the contextual relevance of an 'enlightenment mode' of information provision (Leeuwis and Aarts, 2016) on the biophysical/ecological features of the disease that makes it a collective problem. Both the social learning and communicative intervention studies appreciated this to be an important first step as people need to be convinced why collective action is necessary in the first place. As Röling (2002) also noted, perceived interdependence is a crucial factor and a precondition that urges people to work together.

Interactive communication and deliberation processes

Similar to findings related to social learning, our findings on the role of the different communicative interventions also indicated that interactive communication and deliberation processes are key in the collective management of crop diseases. Through the communicative intervention, the study generated interesting accounts on why some types of stand-alone expert-driven information provision about important technical facts (e.g. collective risks or benefits of spraying) could undermine collective action. This finding is particularly striking because the counterproductive effect of technical information was not evident in the social learning study (Chapter 5) as processes of new information/ knowledge on the disease dynamics and interactive deliberation were interwoven.

Regulatory institutions

A key insight from the social learning study is the importance of regulatory institutions in the collective management of crop diseases. This was not found in the communicative intervention study. Even though interactive communication among farmers was found to discourage free-riding behavior, findings from the social learning study showed that such interactive communication and deliberative processes could further enhance collective action if it leads to some type of coercion or sanctioning system. In this regard, sanctions could play an important role in dealing with non-compliance from individuals who may have relevant technical and social information, and opportunity to communicate with peers but still managed to free-ride. However, as is demonstrated in the same study, a social learning process should lend itself to the emergence or evolution of such institutions within the community.

Implications for development interventions, policy action

The findings of this thesis have practical implications for the design and/or implementation of development and policy interventions and, in particular, for organizing efficient extension and advisory systems.

From centralized extension system to a decentralized learning system

This thesis has revealed that farmers understand crop diseases like late blight and bacterial wilt as an individual farmer's problem that can be managed with farm-level practices. There are different governmental and non-governmental initiatives working to improve the potato production system in the country through advisory and regulatory work with individual potato growers, and mainly through collective schemes such as farmer cooperatives, community-based seed enterprises, QDS (Quality Declared Seed), etc. (Damtew et al., 2018; Hirpa et al., 2010; Gildemacher et al., 2009). These schemes are put in place in a situation where farmers are not aware that they are dealing with contagious crop diseases and that management of these diseases requires collective action. With farmers' limited understanding of the importance of working together to manage crop diseases, the main incentive to participate for farmers in the different schemes and the associated monitoring work might be the likelihood of selling their seed tubers at a slightly higher price or avoiding the risk of rejection of their potatoes by the inspection bodies (Shiferaw et al., 2020). This is problematic in a situation where there is a weak monitoring, regulatory and certification system as farmers tend to focus on getting their seeds to market rather than on the importance of producing disease-free potato for their own benefit and also for the whole potato production system. Designing learning processes that promote knowledge production and sharing on the diseases and their spreading mechanisms, skills in disease diagnosis and (collective) management techniques, including where to find this information, would help farmers understand their interdependency among themselves and also with other actors operating the system. This can then justify, in the eyes of the farmers, the relevance of different institutional mechanisms and monitoring systems (e.g. activity monitoring; development and enforcement of rules and sanctions; resources for monitoring etc.) to collectively and sustainably manage crop diseases (Shiferaw et al., 2020). This brings again the issue of whether such institutional mechanisms have to be externally driven (as it is now the case) or internally developed as part of a facilitated learning process. The best way would be creating the learning space for such institutions to be championed and managed by the community, and the role of external intervention should be geared towards facilitating access to relevant technical information and creating opportunities for interaction and deliberation processes. In this way, farmers will have a chance to reflect and learn from their decisions and actions, and inform their future behavior towards collective action in the management of crop diseases.

The existing extension service pursues an instrumental advisory approach and is focused on the provision of expert information. It then becomes a bit paradoxical that farmers have very limited technical information about the diseases and management practices. In this regard, facilitating access to relevant technical information is still important while the realization of the need to collectively act is the starting point. In the existing extension system, there is little opportunity for farmers to deliberate, negotiate and resolve dilemmas between individual and collective interests. A shift towards more decentralized, horizontal communicative interaction and information sharing practices can facilitate the needed change in social-technical practices in the management of diseases such as late blight and bacterial wilt. Likewise, any envisaged role for ICTs or digital interventions can then be embedded in a broader change from a centralized extension system to a decentralized learning system. In this regard, existing promising initiatives, such as the Agricultural Transformation Agency (ATA) ICT-enabled advisory system, have to place emphasis on using such platforms to amend the existing linear, top-down extension system. A 'technology-deterministic' practice of bringing ICTs into a highly centralized, top-down extension approach might further amplify existing information asymmetry between experts and farmers.

The importance of understanding the context

Research and development projects need to give priority to understanding the problem context when designing interventions in the management of crop diseases. For improvement, knowledge of the current situation should be the starting point. Having a good understanding of the context is crucial in the design of an intervention that fits well in the situation and that adapts with emerging concerns and priorities. In this study, the weak cooperation, top-down information and knowledge sharing culture was instrumental in informing social-technical disease management interventions in the study. The idea of 'knowing the context' needs to be seen from the perspective of informing intervention design processes rather than serve as a benchmark to an already designed or planned intervention. Hence, the recommendation is markedly different from doing the normative baseline study of collecting information to be later used in measuring outcome/impact of an intervention with predefined changes or impact pathways. In this way, interventions or projects have a chance to not only set agendas that are demand-driven, but they can also enhance their adaptive capacity in the face of a dynamic and very uncertain problem situation.

Apart from insights from this thesis, the researcher's practical experience in research and development in the study context has shown him the strong tendency of both governmental and non-governmental actors to rush quickly into designing and/or implementing interventions. There also seems to be an ever-increasing pressure on development practitioners, policymakers and researchers to generate evidence and show impact of their interventions. This urge for delivering impact is understandable when one takes into account the pressing societal needs of rural communities and the apparent time and resource limitations of projects. Nevertheless, a meaningful change can best be realized if the design process and implementation of an intervention is well informed by local realities. Although projects should not necessarily spend half of their life analyzing the situation, there should be a genuine desire and attempt to have a good understanding of local realities. This includes leveraging information from previous projects and also undertaking rigorous documentation of one's own journey to serve as a resource material for future initiatives.

Implications for future research

System-wide learning

The thesis revealed the technical and socio-institutional problem dimensions of the management of late blight and bacterial wilt, also relevant for the management of crop diseases in general. The diagnostic analysis was done at systemic and farmer level. The analysis led to the premise that community-based learning and communicative interventions can catalyze changes in farmers' collective action and may also have the potential to stimulate changes in practice in the wider system. While the thesis generated empirical evidence that changes in collective action can be stimulated at the community level (Chapters 4 and 5), it did not further explore whether and how these changes could instigate changes in collective action in the broader system. For instance, the fact that farmers sought technical backstopping on seed selection from the local research center but decided to deter potential involvement of local government experts in their own monitoring work (Chapter 4) suggests that there are different implications of the community-focused learning for a system-wide change in practice. The fact that diseases such as late blight and bacterial wilt have multiple infection mechanisms may not only complicate the collective problem features of crop diseases but also the type and scale of collective practices that might be needed to effectively manage them. In this regard, further empirical research on how community-level learning interventions in disease management as a 'niche experiment' could instigate systemic learning and change in practices of actors in the broader system would be imperative. The 'system' can include actors operating in potato producing areas or regions, such as regional agricultural offices, regional seed quality inspection offices, local government research centers, farmer-based organizations, NGOs and private sector actors.

Finding a grey area for regulatory institutions

The thesis has shown how regulatory institutions, emerging as part of a social learning process, could promote collective action in the management of crop diseases. However, it is also clear from *Chapter 2* that the management of crop diseases also requires a formal institutional arrangement that is controlled and run by the government, such as disease and seed quality inspection, licensing, and certifications. This means that community-managed disease monitoring and governance systems are expected to complement and comply with the formal arrangements. In this regard, future research in crop disease management strategies could look into how a community-managed disease management systems could interact, interplay, or *bricolage* with the formal institutional arrangements. The *bricolage* processes relate to how newly introduced community-based arrangements and established formal institutions are revised, adapted and socially embedded or abandoned over time (Cleaver, 2012). The understanding of *bricolage* might make it possible to develop recommendations on how promising institutional arrangements at the community level can find their way to influence wider systemic change without being compromised by powerful actors, such as the government.

A room for tailoring communicative interventions

The thesis has emphasized the knowledge-intensive nature of management of crop diseases, the importance of peer-to-peer monitoring and interactive communication to deal with collective action problems. Although the social learning study (Chapter 4) underscored that having new technical knowledge and peer-to-peer monitoring stimulated collective action, findings of the communicative intervention study (Chapter 5) indicated that having similar information can have a counter-productive role if not supported by interactive communication. Future research could focus on exploratory investigation of *why* farmers make sense of the technical or the monitoring information the way they do. This sense-making could be shaped by various social factors such as trust issues, norms of reciprocity or previous community experiences in collective engagement. This could add to the understanding of why farmers, for instance, pursue individual actions rather than going for actions that ensure collective benefits (Ostrom and Walker, 2003). An in-depth contextual understanding of these factors could help in the design of interactive communication and negotiation processes that are tailored to a specific community or problem context.

References

Baggio, J., Barnett, A., Perez-Ibarra, I., Brady, U., Ratajczyk, E., Rollins, N., Rubiños, C., Shin, H., Yu, D., Aggarwal, R. and Anderies, J., 2016. Explaining success and failure in the commons: the configral nature of Ostrom's institutional design principles. *International Journal of the Commons*, *10*(2).

Burke, J.J., 2017. Growing the Potato Crop. Vita, Equity House, Upper Ormond Quay, Dublin, Ireland.

Cox, M., Arnold, G. and Tomás, S.V., 2010. A review of design principles for community-based natural resource management. *Ecology and Society*, *15*(4).

Cleaver, F., 2012. Development Through Bricolage: Rethinking Institutions for Natural Resource Management. London: Earthscan/Routledge.

Gee, J.P. and Green, J.L., 1998. Discourse analysis, learning, and social practice: A methodological study Review of Research in Education (Vol. 23, pp. 119–169). *Washington DC: American Educational Research Association*.

Gildemacher, P.R., Kaguongo, W., Ortiz, O., Tesfaye, A., Woldegiorgis, G., Wagoire, W.W., Kakuhenzire, R., Kinyae, P.M., Nyongesa, M., Struik, P.C. and Leeuwis, C., 2009. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. *Potato research*, *52*(2), pp.173-205.

Hirpa, A., Meuwissen, M.P., Tesfaye, A., Lommen, W.J., Lansink, A.O., Tsegaye, A. and Struik, P.C., 2010. Analysis of seed potato systems in Ethiopia. *American journal of potato research*, *87*(6), pp.537-552.

Koontz, T.M., 2014. Social learning in collaborative watershed planning: the importance of process control and efficacy. *Journal of Environmental Planning and Management*, *57*(10), pp.1572-1593.

Leeuwis, C. and Aarts, M.N.C., 2016. Communication as intermediation for socio-technical innovation. *JCOM Journal of Science Communication*, *15*(6).

Leeuwis, C. and Pyburn, R., 2002. Social learning for rural resource management. *Wheelbarrows full of frogs: Social learning in rural resource management*, pp.11-21.

Miller, J.S., Nolte, P., Olsen, N., Miller, T., Bohl, B., Thornton, M., 2006. Late Blight Management Action Plan for Potatoes. University of Idaho Extension.

Leeuwis, C., Cieslik, K.J., Aarts, M.N.C., Dewulf, A.R.P.J., Ludwig, F., Werners, S.E. and Struik, P.C., 2018. Reflections on the potential of virtual citizen science platforms to address collective action challenges: Lessons and implications for future research. *NJAS-Wageningen Journal of Life Sciences*, *86*, pp.146-157.

Ostrom, E., 2010. Polycentric systems for coping with collective action and global environmental change. *Global environmental change*, *20*(4), pp.550-557.

Ostrom, E., and Walker. J., 2003. *Trust and Reciprocity: Interdisciplinary Lessons from Experimental Research*. New York: Russell Sage.

Röling, N., 2002. Beyond the aggregation of individual preferences. *Wheelbarrows full of frogs: social learning in rural resource management. Koninklijke Van Gorcum, Assen, Drenthe, The Netherlands*, pp.25-48.

Tafesse, S., Lie, R., van Mierlo, B., Struik, P.C., Lemaga, B. and Leeuwis, C., 2020. Analysis of a Monitoring System for Bacterial Wilt Management by Seed Potato Cooperatives in Ethiopia: Challenges and Future Directions. *Sustainability*, *12*(9), p.3580.

A

Appendices

Synthesis

Summary

Despite previous attempts by governmental, non-governmental and research organizations, potato late blight and bacterial wilt are still rampant in Ethiopia, compromising potato production in the country. This thesis starts with the argument that to be able to effectively manage such disease, it is imperative to have a fresh perspective and a deep enough understanding of the problem situation which, in turn, can inform the type of disease management strategy that needs to be put in place. With this objective in mind, the study set out to understand the problem of late blight and bacterial wilt with a social-technical lens, and to explore the roles that different social-technical interventions play in the management of crop diseases, particularly late blight. Consequently, the first two empirical chapters (Chapters 2 and 3) of the diagnostic phase examine the multidimensional problem situation of late blight and bacterial wilt management. In the intervention phase (Chapters 4 and 5), different types of learning and communicative interventions are studied.

The central tenet of *Chapter 2* is that the management of late blight and bacterial wilt is a complex problem, and that addressing complex challenges require actors to understand the multi-dimensional problem aspect of crop diseases, such as late blight and bacterial. The study assesses actors' understanding of the technical and institutional dimensions of the complex problem situation of late blight and bacterial wilt management, and how their understanding of the situation facilitates or hinder collective action in the management of the two diseases. The chapter highlights how actors essentially overlooked key systemic problems while their management responses are mainly geared towards uncoordinated short-term reactions. Limited recognition of interdependency and a generally top-down intervention approach stand out to be key systemic factors. The chapter concludes that a bottom-up and participatory disease management approach can serve as a 'local' solution to a wider systemic problem and can facilitate collective action to deal with the problem. The chapter also suggests that more insights into farmers' knowledge and associated practices can lead to the elaboration of specific recommendations to catalyze learning and collective action at the community level.

Chapter 3 adds to the understanding of the problem situation and further explores requirements for a bottom-up, collective management strategy for the two diseases. The study assesses the knowledge and associated practices of farmers, providing insights into relevant knowledge and practice gaps and ideas for the types of learning processes that might be required. The chapter argues that farmers' practices are informed by their knowledge about the diseases and demonstrates how farmers' limited knowledge is influencing their ability to effectively deal with the diseases. The study emphasizes that learning approaches which reveal the technical aspects of the diseases and learning

processes that highlight interdependency and the benefits of collective action are an important requirement if communities are to forge an effective management strategy.

Chapter 4 takes late blight as a case, arguing that learning has to simultaneously address the social and technical features of crop disease management if it is to foster collective action at the community level. On the one hand, relevant technical knowledge of the biophysical and epidemiological nature of diseases and of available management options is key in informing technical management practices while, on the other hand, the management of shared problems requires a re-ordering in social organizations that shape and modify social practices. We found that learning about the life-cycle and mobility of the late blight pathogen played a key role in stimulating collective action. Farmers were able to reach agreements on novel social-technical practices, such as team field scouting for late blight detection, monitoring individual management practices and sanctioning non-compliance. The chapter also demonstrates that regulatory institutions can emerge as part of a social learning process. Accordingly, the chapter highlights that institutional arrangements in the form of monitoring systems and sanctions would best stimulate collective action if they emerge and evolve within communities rather than being imposed externally.

Taking a 'public bad' perspective to crop disease such as late blight, *Chapter 5* investigates the role of different types of communicative intervention on collective action performance of farmers in their efforts to manage late blight. Three types of communicative practices were experimented with in a game experiment that discerns the role of information provision from that of interactive communication that appears to be woven together in social learning processes.

The chapter highlights that the provision of technical information about the risk and benefits of collective management practices, and monitoring information about the management practices of other farmers can be counterproductive for collective action unless it is complemented with interactive communication that is internally governed or managed by communities. It concludes that expert advisory services and expert provision of relevant technical and social information has to be supported with deliberation processes. These deliberation processes would help in making the best of advisory services and monitoring practices that could otherwise negatively affect collective action performance in managing crop diseases.

With its empirical chapters, the thesis demonstrates the complex, multi-dimensional and collective nature of crop disease management in general and that of late blight management in particular. A good understanding of the complexity is a useful starting point to explore options and leverage points for disease management interventions. In this

regard, stimulating social learning processes and re-configuring communicative practices are shown to be promising interventions towards collective action in the management of crop diseases.

Appendix

Regression outputs of the different communicative interventions in Chapter 5

Table A1: Technical information about interdependency and spraying threshold reached.

	% of farmers in groups reaching threshold	*P*-value
Non-intervention mean	**0.44**	
Technical information about interdependency	-0.11 (0.0692)	0.125
Male dummy	-0.75 (0.120)	0.533
Education level	0.01 (0.048)	0.825
Age in years	0.00 (0.004)	0.981
Household size	-0.01 (0.020)	0.480
Potato farm size	0.01 (0.053)	0.833
Perceived late blight seriousness	0.02 (0.087)	0.860
Mainly seed producer	0.08 (0.205)	0.371
Mainly ware producer	-0.01 (0.108)	0.956
Mobile phone ownership	0.02 (0.108)	0.874
Smart phone ownership	-0.07 (0.130)	0.570
Kebele fixed effects	Yes	
Observations	**90**	
R-squared	**0.679**	

Standard errors are reported in parenthesis.

Table A2: Technical information + Monitoring information and spraying threshold reached.

	% of farmers in groups reaching threshold	*P*-value
Control group mean	**44.44**	
Technical information about interdependency + Monitoring information	-0.10 (0.037)*	0.012
Male dummy	0.19 (0.070) *	0.008
Education level	-0.00 (0.024)	0.979
Age in years	0.00 (0.002)	0.672
Household size	-0.01 (0.010)	0.387
Potato farm size	-0.03 (0.029)	0.289
Perceived late blight seriousness	0.02 (0.048)	0.956
Mainly seed producer	-0.00 (0.046)	0.990
Mainly ware producer	-0.02 (0.133)	0.904
Mobile phone ownership	-0.08 (0.055)	0.146
Smart phone ownership	0.02 (0.067)	0.786
Kebele fixed effects	Yes	
Observations	**90**	
R-squared	**0.910**	

Standard errors are reported in parenthesis. * $p < 0.05$.

Table A3: Monitoring information and spraying threshold reached.

	% of farmers in groups reaching threshold	*P*-value
Control group mean	**44.44**	
Monitoring information	0.13 (0.040) *	0.002
Male dummy	-0.02 (0.089)	0.857
Education level	-0.02 (0.026)	0.352
Age in years	-0.00 (0.002)	0.976
Household size	0.01 (0.009)	0.496
Potato farm size	-0.01 (0.032)	0.724
Perceived late blight seriousness	-0.09 (0.055)	0.119
Mainly seed producer	-0.01 (0.049)	0.829
Mainly ware producer	-0.00 (0.110)	0.974
Mobile phone ownership	-0.06 (0.072)	0.386
Smart phone ownership	-0.08 (0.071)	0.286
Kebele fixed effects	Yes	
Observations	**90**	
R-squared	**0.912**	

Standard errors are reported in parenthesis. * $p < 0.05$.

Table A4: Technical information about interdependency + Monitoring information + Group Communication and spraying threshold reached.

	% of farmers in groups reaching threshold	***P*-value**
Control group mean	**44.44**	
Technical information + Monitoring information + Group Communication	0.12 (0.039) *	0.003
Male dummy	-0.07 (0.105)	0.484
Education level	-0.01 (0.027)	0.823
Age in years	0.00 (0.002)	0.856
Household size	-0.00 (0.009)	0.634
Potato farm size	-0.01 (0.030)	0.815
Perceived late blight seriousness	0.04 (0.055)	0.462
Mainly seed producer	-0.01 (0.054)	0.906
Mainly ware producer	-0.05 (0.147)	0.715
Mobile phone ownership	0.03 (0.065)	0.700
Smart phone ownership	-0.01 (0.070)	0.940
Kebele fixed effects	Yes	
Observations	**90**	
R-squared	**0.903**	

Standard errors are reported in parenthesis. * $p < 0.05$.

Acknowledgements

My PhD journey started and ended on the time and the way I wanted it! I must extend my immeasurable gratitude and deepest appreciation to all those who helped that happening.

I am very grateful of the INREF (Interdisciplinary Research and Education Fund) funded EVOCA (Environmental Virtual Observatories for Connective Action) research program and CIP (International Potato Center) for jointly funding my PhD training. To say the obvious, it was impossible for me to enroll in the PhD program by the time I wanted to go to a PhD school if it wasn't for this funding.

I am extremely thankful of my PhD supervisory team. I heard stories that a big supervisory team could pose a problem for PhDs but my experience is otherwise. Prof, Cees Leeuwis, my promoter, little time goes by without thinking about our first email exchanges when I was aggressively searching for PhD opportunities in 2015. In hindsight, I get blown away by the fact that you constantly responded to my emails which are just coming from a young man from Africa you don't even know. Our communication eventually bore fruit when I became one of your KTI and EVOCA PhD students. Thank you for being a constant source of inspiration through your scientific work and character, and your mentorship over the years. My second promoter, Prof Paul C. Struik, your efficiency is beyond my compression. It became a tradition that all my supervisors will work on the document you would first share with your comments. Not only that I gained knowledge about the science of crop/ potato diseases from you, I have learned a lot about work ethics that I can use in the years to come. Dr. Barbara van Mierlo, working with you was quite a journey. Your stepwise coaching style and the attention you have for details made my PhD trajectory an immense and interesting learning experience. When I get lost, your extraordinary sense making skill was crucial to drag me out of my own mess. Dr. Berga Lemega, you are one of the modest and sincere people I have worked with. As a sandwich PhD, I can't even imagine what our field and desk work back home would have been like without your relentless support and guidance. Your enormous knowledge and experience of the Ethiopian potato sector was quit instrumental in contextually grounding my PhD work. Dr. Rico Lie, you have been part of my supervisory team from the beginning till the end. You diplomatic coaching approach definitely helped me to successfully navigate the challenges of working with a big supervisory team. Your office was very welcoming and I hope I didn't abuse the freedom by knocking now and then.

I would like to thank all my PhD colleagues and friends at KTI/CPT floor, on EVOCA project and the university. Mirjam, Mariette, Andy, Faith, Nyamwaya, Domina, Marylin, Aboubakar, Jan, Jean, Kelly, Chris, Richard, Emanuel, Diana, Paola, Onno, Horacio, Mariola, Marie, Mikinay, Sanne, Yodit and George. Without you, my PhD life at the university could not have been the same. I have so many memorable moments with you all. Special thanks goes to Shiferaw Gobena who was also my EVOCA case study partner.

A handful of pleasant people at the CPT secretariat and in the EVOCA management deserve a sincere thanks. Inge Ruisch, Vera Mentzel, Mirjam Cevat, Bea Prijn, Germaine Dunselman. I thank you all very much for helping me focus on my PhD by taking care of issues that come along with the PhD project. Passing by the secretariat office or chatting with you on the corridor was a needed distraction from a stressful PhD work. Dr. Katarzyna Cieslik, you were an amazing and compassionate colleague, work partner and manager.

A work of this magnitude cannot be satisfactorily completed without the support from my family. I have always been grateful for my father and mother who have the greatest influence on who I am. My sisters, you have always looked after me and my brother, Daniel, you have been my role model in many ways. Hana, the mother of my two children, thank you very much for being a dedicated mother and for taking care of the kids in my absence.

At last but not least gratitude goes to Ethiopian potato growing farmers, extension workers, government and non-government experts involved in the potato sector and researchers in the national research system without whose participation and support my PhD study couldn't have been realized.

About the Author

Elias Damtew Assefa was born on September 11, 1983 in Addis Ababa, Ethiopia. He joined Haramaya (then Alemaya) University and obtained his bachelor in Animal Science in 2005. After graduation, he worked in the livestock marketing sector in governmental and non-governmental organizations before he went back to the same university in 2010 to pursue his masters in Agricultural Information and Communication Management. His master internship in 2011 on a joint project of International Livestock Research Institute (ILRI) and International Water Management Institute (IWMI) linked him with the CGIAR system. After he finished his masters in 2012, he worked as a Research Associate at ILRI on social-institutional innovations in agricultural systems up until he joined the Knowledge, Technology and Innovation Group in Wageningen University as a PhD candidate in January 2016.

Elias Damtew Assefa
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department / Institute	Year	ECTS *
A) Project related competences			
EVOCA modules	Wageningen School of Social Sciences (WASS)	2016	6
PhD research proposal	WUR	2016	6
1st EVOCA workshop in the Netherlands	EVOCA Management	2016	1
2nd EVOCA workshop in Ghana	EVOCA Management	2017	1
3rd EVOCA workshop in the Netherlands	EVOCA Management	2018	1
4th EVOCA workshop in the Netherlands	EVOCA Management	2019	1
'A systems thinking approach to the diagnosis of the problem of potato bacterial wilt and late blight in Ethiopia' Poster presentation	18th Triennial Symposium In-ternational Society on Tropical Root Crops (ISTRC)	2018	1
Questionnaire Construction, YRM 65300	Research Methodology, WUR	2016	1.5
Research internship	Cornell university, school of Integrated Plant Sciences	2018	4
B) General research related competences			
Research Methodology: from topic to proposal	WASS	2016	4
Qualitative Data Analysis with Atlas-ti: a hands-on practical	WASS	2016	1
Interpretive research Design	WASS	2016	3
WASS Introduction Course	WASS	2016	1
Basic Statistics	Production Ecology and Re-source conservation (PE&RC)	2016	1.5
Extreme Citizen Science	WASS and University College London	2016	1.3
Information Literacy PhD including Endnote Introduction	Wageningen UR library	2016	0.6
Effective strategies for academic writing	EVOCA Management	2018	1.3
C) Career related competences/personal development			
Convener EVOCA fourth workshop	CPT, WUR	2019	1
Article review on Wageningen Journal of Life Sciences (NJAS) special issue	KTI, WUR	2018	1
Total			**38.2**

* One credit according to ECTS is on average equivalent to 28 hours of study load

The PhD study is conducted under a research program of Responsible life science innovations for development in the digital age: EVOCA that is funded by Wageningen University International Research and Education Fund (INREF). I would like to acknowledge INREF and the International Potato Center (CIP) for co-funding my the Ph.D. training. Additional funding was provided by the CGIAR Research Program on Roots, Tubers and Bananas (RTB) and US Agency for International Development (USAID) Federal Award no. 663-G-00-09-00420.

Cover design: Luc Dinnissen
Printed by: Digiforce / ProefschriftMaken.nl
Layout by: Dennis Hendriks / ProefschriftMaken.nl