Farmers in the Lead

Assessing effectiveness of participatory experimentation in Tigray, Northern Ethiopia

Richard Kraaijvanger

Propositions

1. Food aid used as forage contributes to crop productivity.
   (this thesis)

2. A citation index approach gives illiterate farmers a voice.
   (this thesis)

3. The most relevant output of empirical research is surprise.

4. Interdisciplinary interaction between social and natural sciences is like ice skating: slippery ice is best for all.

5. Despite fair trade labels, trade can never be fair.

6. Rural development workers often behave like tourists.

Propositions belonging to the thesis, entitled

'Farmers in the Lead: Assessing effectiveness of participatory experimentation in Tigray, Northern Ethiopia'.

Richard Kraaijvanger

Wageningen, 23 October 2018.

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Richard Kraaijvanger

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To all farmers trying to make a living for their families

out of work of their hands,

the soil they live on

and everyday’s uncertainties.

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Abstract

In sub Saharan Africa agricultural production is low and considered a main focus for development as concerns about food security and crop yield are evident and currently became even more emphasized by the impact of climate change. Over the years agronomic research definitely has been successful in identifying crop productivity constraints and addressing these by technological solutions and recommended practices. Still, real impact on crop yield appears limited, despite numerous efforts to support effective implementation of such recommendations. Farmers in many cases hesitated to adopt the technologies proposed, for example, as they considered them too risky. At the same time, differences in backgrounds of farmers and researchers resulted in different choices made and consequently in different pathways to development. Participatory experimentation, in which farmers and researchers co-operate, is often proposed as an interesting option to increase understanding between researchers and scientists and considered well suited to develop options to upgrade farming systems within a local context. Involving farmers in the development of recommendations matching with local conditions is assumed to make future implementation more likely and sustainable. Furthermore, farmers' involvement in participatory experimentation is expected to result in empowerment. The impact of participatory experimentation in the context of increasing crop productivity can be divided into two components: (1) contributions to higher yield and sustainability of the agricultural production system and (2) contributions to the social and human capital of the farmers involved. In our research project in Tigray, Northern Ethiopia, effectiveness of participatory experimentation was assessed with respect to these contributions and contextual relevance. Furthermore, better understanding of the participatory process itself and the agronomic outcomes of the experiments was sought. In our research project 16 groups of farmers, distributed over four locations, were involved for four years in participatory experimentation. Next to monitoring the experiments through various measurements, also the process and the farmers involved were monitored through interviews and observation. Participatory approaches differ in the level of control of the process by the farmers involved; in our research project an approach was followed in which farmers were unambiguously in the lead: they selected the technologies they wanted to assess within their local context; researchers involved concentrated on facilitation of the

participatory process. Identification of constraints and opportunities is an essential step in most research processes, at the same time methods applied are diverse. In a review of 16 papers we identified three clusters of methods on the basis of two variables typifying these methods: control over de research process and represented opinion. In a case study we compared, as a follow up, three different methods for identifying crop productivity constraints: contextual data collection, individual surveys and focus group discussion. Congruency between the methods was not found significant, and of these methods only focus group discussion responded to contextual diversity. Combined the review and case study demonstrated that process control and represented opinion had a manifest impact on generated outcomes. In our study area we applied focus group discussion in all four locations to identify productivity constraints and opportunities. Outcomes in the form of mind maps were quantified to allow comparison between the locations. In all locations soil fertility measures were considered a main opportunity; all other categories of constraints and opportunities were diverse for the locations involved. Farmers were in groups involved in participatory on-farm experimentation to arrive at best practices matching with local preferences, complexity and context. Experiments conducted were documented for yield and various soil, land and management related factors. Analysing the outcomes of the on-farm experiments indicated that the (high) variability in grain yield observed was very location specific and related to treatment effects, local management, climate and soil conditions. Furthermore, relationships between different soil properties (organic-C, P and K) and response to fertilizer inputs were indeterminate, but this was not the case for N-total. Developing clear recommendations on the basis of the experiments consequently was not possible. Understanding choices made by farmers in experimentation processes is important to find reasons why farmers often hesitate to adopt specific practices. We therefore monitored the 16 groups (of five farmers) during four years and found that the groups followed a very rational context-rooted strategy that differed considerably from that of the researchers involved. Consequently, in participatory experimentation, involvement of farmers in defining the actual experimental design is mandatory in order to deal with local preferences and context. Experimental outcomes in the form of yield responses and nutrient balances were analysed from different perspectives: farmer, agronomic and environmental. All three perspectives indicated that gradually strengthening the *existing farming system by using fertilizers, organic manure and legume fallows will support crop productivity while addressing at the same time other aspects of sustainability like food security and profitability. Farmers were involved in participatory experimentation for four years with minimum external intervention; in contrast to our initial expectations, all groups continued their involvement and indicated the ambition to proceed on their own. Of a set of factors that might influence farmers' involvement, only benefits in the form of good responses were overall important; all other factors were highly variable among the groups. Outcomes achieved for the farmers involved were found substantial and relevant; yield increase, knowledge and confidence being most important. Next to this, participatory experimentation resulted in better mutual understanding of perspectives held by farmers and scientists, reducing in this way the gap between their views. To arrive at effective participation, approaches should be group specific and based on open processes in which feedback is essential and responsibilities are delegated to the farmers in all research phases. Facilitation is essential in this but given the diversity of groups and the context in which they operate, blue-print approaches are not likely to be effective. Human-social outcomes and contextual relevancy were extremely influenced by an explicit choice for maximum involvement of farmers in all phases of the experimentation process; farmers' learning consequently not only related to knowing the best way, but also towards confidence in finding the best way. Participatory experimentation, therefore, not only constitutes a feasible option to improve farmer livelihoods by combining development of site specific recommendations with capacity building, but also has a clear potential to act as a change agent to trigger transitions towards more sustainable livelihood systems.*

1 Introduction

1.1 Crop production and development

The global environmental, political, social and economic situation is under continuous pressure: conflicts, poverty, health and environment put a heavy toll on the global human community. At the same time, many of these concerns are interrelated. In 2000 the Millennium Development Goals (Love et al., 2006; Sahn and Stifel, 2003; UN, 2015) were formulated, followed by the Sustainable Development Goals in 2015 (Sustainable-Development, 2015). In both frameworks considerable emphasis was put on the issues of ending hunger, food security and achieving sustainable agriculture. In relation to food security, crop production continues to be a major concern of rural communities in developing countries. The recent Arabic uprisings demonstrated that increasing food prices may cause major changes in the political arena. This is one of the reasons why nations aim at achieving food security (Frankema, 2014). India and China, for example, increased their food production successfully by using the high-external-input-paradigm of the Green Revolution. Despite clear increases in crop productivity, recently debates emerged on the sustainability of these successes. In this context, especially social (McIntyre et al., 2009) and environmental dimensions of sustainability (Altieri et al., 2012; Koohafkan et al., 2012) are questioned.

In sub Saharan Africa (SSA) agricultural production is a main development focus (African-Development-Bank, 2016; Ajakaiye and de Janvry, 2010; FARA, 2014; Worldbank, 2007) as concerns about food security and crop production are evident (Flora, 2010). In contrast to other parts of the world, sub Saharan African countries did not achieve significant increase in crop yield (Jama and Pizarro, 2008) and efforts like the Alliance for a Green Revolution in Africa (AGRA) (Holt-Giménez, 2008)) and N2Africa (N2Africa, 2016) consequently aim at increasing crop yield. To do so, a transformation of existing agricultural systems into more productive ones is pursued, mostly including increased use of external inputs. However, until now the intensification paradigm has failed to bring about significant change in SSA (Giller et al., 2011). This is because agricultural productivity faces numerous constraints, which are diffuse and rooted in local complexity and context. The urgency of addressing the “wicked” problem of low crop productivity is even more emphasized by the impact of climate change (Ajakaiye and de Janvry, 2010; Brooks, 2014; Tittonell et al., 2012).

Crop productivity constraints can be agro-ecological and socioeconomic in nature. Agro-ecological constraints relate to soil, landscape and climate properties. Examples of agro-ecological constraints are low soil fertility (FAO-ITPS, 2015), variable onset and duration of rains (Frankl et al., 2013; Gebrehiwot et al., 2011), incidence of pests and diseases and availability of manure. Socioeconomic constraints affecting crop production are connected with a wide range of issues like land tenure, inflexible markets, transportation, farm and family size, supply of agricultural inputs, labour shortage, credit availability, education, technical knowledge and extension support (Ehui and Pender, 2005). In other cases, subsidies and food aid are responsible for low food prices, resulting in limited incentives to strive for higher crop productivity.

Tigray in Northern Ethiopia is exemplary for sub Saharan Africa in the sense that crop productivity is low, constraints are many, food aid essential (Van der Veen and Tagel, 2011) and land degradation severe (Ciampalini et al., 2012; Hengsdijk et al., 2005; Virgo and Munro, 1978). At the same time, extension workers of the Bureau of Agriculture and Rural Development (BoARD) and the international community, for example, through the Millennium Villages Project (Denning et al., 2009; Jama and Pizarro, 2008; Sanchez and Swaminathan, 2005), were actively engaged in improving this situation, however, mostly with limited success (Abate et al., 2011).

1.2 Farmers and researchers

Agronomic research definitely has been successful in identifying general productivity constraints, addressing these in most cases by technological solutions and recommendations originating from Green Revolution technology packages (Tittonell and Giller, 2013). Recommendations, however, have no universal validity and implementing these recommendations in sub Saharan Africa is difficult due to non-uniform, site specific conditions (Dea and Scoones, 2003; Giller et al., 2008; Ronner, 2018). In past decades much effort has been made to support effective implementation of recommendations, but real impact on crop yield still appears limited (Dalal-Clayton and Dent, 2001; Giller et al., 2011; Giller et al., 2009). Farmers in many cases hesitated to adopt the technologies proposed, which were often introduced in a one-size-fits-all format, as they considered them too risky (Frankema, 2014; Gebrehiwot and van der Veen, 2015; George, 2014; Rigolot et al., 2017).

Farmers and researchers both have comparable objectives in achieving sustainability, increasing crop production and achieving food security. Still, in looking for and selecting feasible options to achieve food security and sustainability, differences in backgrounds of farmers and researchers are likely to result in different choices made and, as a consequence, different pathways to development. At the same time, communication between farmers and researchers is often troublesome and reference frameworks and perception of risks might be completely different (Van Asten et al., 2009). Farmers often use rationales different from the ones held by researchers and other stakeholders in development work (Ramisch, 2012). Such differences complicate the adoption of novel technology by farmers; differences may even become more pronounced when researchers are in the lead of studies aiming at developing and implementing novel technologies in local rural contexts. Projects focusing on Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2010) and Conservation Agriculture (CA) (Astatke et al., 2003; Giller et al., 2009; Nyssen et al., 2011) provide examples of the implementation of such technologies.

Farmers in SSA not only face a "*yield gap*" (Henderson et al., 2016; van Noordwijk and Brussaard, 2014), i.e. the gap between actual and attainable (or potential) yield (Mueller et al., 2012; Van Ittersum et al., 2013), but there is also a pronounced difference between researchers' and farmers' perspective on sustainable ways to increase crop production. This *"perspective gap"* can be bridged from both sides. Scientists, for example, could opt for a more in-depth understanding of local context, while farmers could expand their traditional reference framework, to allow more effective sharing of their views and (traditional) knowledge with scientists (Biggs, 2007; Biggs and Matsaert, 1999; Chambers and Jiggins, 1987b).

1.3 Participatory approaches

Participatory approaches, in which farmers and researchers co-operate, are often proposed as a suitable option to increase understanding between researchers and scientists (Almekinders and Hardon, 2006; Anderson et al., 2016; Morris and Bellon, 2004; Spielman et al., 2008). In general, participatory approaches aim to involve farmers more in development processes. In this collaboration complementarity (Sumberg et al., 2003) as well as synergy (Hoffmann et al., 2007) are considered important aspects.

Ways to implement participatory approaches for improving crop productivity are manifold, with each method having advantages and disadvantages. Examples range from Farmer Field Schools (Braun et al., 2000) and Local Farmer Research Groups (Probst, 2002) to demonstrations simply showing farmers what-to-do (Misiko, 2009; Ramisch, 2012). Participatory approaches are considered well suited to develop options to upgrade farming systems within a local context (Beyene et al., 2006; Shiferaw et al., 2009). Involving farmers in the development of recommendations that match with local conditions makes, as a consequence, future implementation more likely and sustainable (Farrington, 1995; Van Mele, 2008).

Initiatives aiming at such involvement are usually framed as participatory experimentation, a form of Action Research in which farmers and researchers co-operate in addressing constraints, for example, in relation to crop productivity and crop breeding (Almekinders et al., 2009; Faure et al., 2014). In Action Research context is an essential component of the problem (Baskerville and Wood-Harper, 1996), which makes it particularly suitable to address the complexity in which farmers operate. Despite shared research topics, preferences and priorities of farmers and researchers, even in the setting of Action Research, may diverge: farmers tend to focus more on direct (short-term) outputs, whereas scientists also have objectives relating to generalization (Baskerville and Wood-Harper, 1996; Biggs and Smith, 1998; Ramisch, 2012; Richards et al., 2009; Van De Fliert and Braun, 2002).

Another important outcome of farmers' involvement in participatory experimentation is that they feel more responsible and confident about their own development. Ideally, such a situation might result in the formation of formal and informal institutions supporting development (Chambers and Jiggins, 1987b; Dalal-Clayton and Dent, 2001). At the same time, indigenous knowledge, of which researchers might be unaware, is mobilized (Corbeels et al., 2000) and becoming explicit (Hoffmann et al., 2007).

The impact of participatory experimentation in the context of increasing crop productivity can thus be divided into two components: (1) contributions to higher yield and sustainability of the agricultural production system and (2) contributions to the social and human capital of the farmers involved. Contributions under (1) are also referred to as direct benefits (Douthwaite et al., 2003), functional aspects (Hellin et al., 2008) or instrumental knowledge (Duveskog et al., 2011); contributions under (2) are referred to as empowerment (Hellin et al., 2008) or individual/collective agency (Duveskog et al., 2011).

Most participatory interventions, currently, focus on selecting and implementing technology; most of the technologies are assumed to be available and farmers are considered to select "*best bets*" from a "*basket full of options*" (CASCAPE, 2014a; Giller et al., 2011). Adapting and developing technologies and especially the aspect of empowerment are, however, given less attention (Martin and Sherington, 1997; Sperling et al., 2001), which might affect sustainability of interventions.

In participatory approaches the balance between researcher and farmer inputs and responsibilities clearly varies: in some cases participatory experimentation is merely thought of as on-farm trials, controlled by researchers, whereas in other cases farmers are in control of almost all phases of the process (Ayenor et al., 2004). In debates about participation, stakeholder selection (Reed et al., 2009), power relations (Mosse, 2001) and the level of participation are often critically questioned; more participation is not always considered better (Neef and Neubert, 2011).

1.4 Rationale of the research

The food security situation in Tigray, exemplary for many other parts of the world, is under continuous pressure as local crop production is not sufficient to cover the requirements of the rural population (Ehui and Pender, 2005; Gebregziaher et al., 2013; Gebrehiwot and van der Veen, 2015). Options for improving crop yield in Tigray are currently implemented as technology packages (Berhanu and Poulton, 2014; Segers et al., 2008) that aim at alleviating constraints related to soil, water and nutrient management, under the assumption that actual yield is not primarily restricted by agro-ecological conditions (Nyssen et al., 2004). However, as one-size-fits-all approaches were often not successful (Abate et al., 2011; Kebede et al., 2015; Spielman et al., 2010), a careful selection of suitable technologies adapted to specific contexts is required. Participatory approaches are presumably particularly suitable to achieve such objectives, since local context is addressed better than in conventional, more top-down and linear extension approaches.

Although participatory approaches have been promoted in many cases, relatively little is known about its real-life achievements and effectiveness: empirical evidence is lacking (Farrington et al., 1997; Leeuwis, 2000; Martin and Sherington, 1997; Mayoux and Chambers, 2005; Morris and Bellon, 2004; Reed, 2008; Sherman and Ford, 2014; Smajgl and Ward, 2015; Van Der Wal et al., 2014). Literature is either focusing on do's and don'ts or puts participatory approaches into a highly theoretical framework which does not relate directly with day-to-day reality of intervention work (Duraiappah et al., 2005; Hoffmann et al., 2007; Kapoor, 2002; Parfitt, 2004; Williams, 2004).

Different dimensions of effectiveness can be considered, depending on objectives defined (Kaufman et al., 2014; Martin and Sherington, 1997; Sherman and Ford, 2014). Scholars discussing participatory approaches often differentiate between: (1) a functional dimension relating to outputs in terms of, for example, yield, improved practices, sustainability and agronomic recommendations and (2) a human-social dimension relating to, for example, empowerment (Farrington, 1998; Farrington and Nelson, 1997; Hellin et al., 2008). In the context of my project I therefore wanted to know if participatory experimentation indeed, in line with its claims, was effective in achieving change (as compared to non-intervention) with respect to both functional and human-social aspects.

Participatory approaches differ in the level of control by the farmers involved (Biggs, 1989; Pretty, 1995). In my research project participatory experimentation stood central and in order to assess its effectiveness an approach was followed in which farmers were unambiguously in the lead: they selected the technologies they wanted to assess within their local context.

1.5 Research questions

In my research project participatory experimentation was applied with multiple objectives: to arrive at meaningful recommendations for increasing crop yield, to contribute to farmers' learning, to make them more confident and to equip them with adaptive capacity for the future. In relation to achieving these objectives, I hypothesized that when farmers are in the lead of experimentation and implementation of new yield enhancing technology, this will result in: context specific adaptation; increased crop yield; adoption of new practices and novel technology; empowerment.

The research questions of this project were defined as assessing effectiveness of participatory experimentation in terms of:

(1) relevancy of outcomes for the farmers involved and the context in which they operate;

(2) change resulting from involvement in participatory experimentation with respect to functional aspects;

(3) change resulting from involvement in participatory experimentation with respect to human-social aspects.

Although my research project was designed primarily to assess effectiveness, it at the same time offered opportunities for generalization at meta-level. Therefore, as a researcher involved in participatory experimentation, I wanted to embark on two other research questions that related to process and agronomic context:

(4) what are characteristics of the process of participatory experimentation and what factors influence this process;

(5) what are the relationships between on-farm experimental outcomes and different agronomic factors.

1.6 Set up of the research project

In my research project I engaged in participatory experimentation with farmers with the ambition to assess effectiveness of participatory experimentation. The project was shaped as a social experiment. Important requirements to answer my research questions were: systematic monitoring of farmers, process and outcomes throughout the project and comparison of (farmer) participants with a control group of not participating farmers.

In total 16 groups of farmers, distributed over four *woredas* (regional administrative units, see also Fig. 1.2), were involved in my research project. The members of these groups were selected on the basis of suggestions from BoARD and were living in the same *cushet* (neighbourhood). The actual process started in 2008 with a workshop session in which the farmer groups focused explicitly on the identification of constraints and opportunities relating to the productivity of their crops. Then, over a period of five years, the farmer groups were involved in four fully monitored experimentation cycles. In each of these cycles (constituting of a clear design, experimentation and evaluation phase) outcomes were generated that served as an input for the next series of experiments. A fifth (final) cycle was only monitored in retrospect through interviews with participating farmers.

A main choice in setting up participatory work is the distribution of responsibilities between farmers and researchers, i.e. the degree of participation. In my case I decided to take a more extreme position to allow comparison between the groups and to determine the potential of participatory experimentation. The approach therefore focused on maximum involvement of farmers: they had a full mandate for all important decisions in the experimentation process and inputs of scientists and other stakeholders were restricted to facilitation of the process.

The main participatory tool applied was Focus Group Discussion, in which farmers indeed exerted (almost) full control over the decision-making process. In this way farmers were allowed to control experimentation and to address local context. In addition, Focus Group Discussion was assumed to support social learning by creating a forum for sharing opinions, for negotiation, for distributing responsibilities and making agreements (Chioncel et al., 2003; Kaplowitz and Hoehn, 2001; Kidd and Parshall, 2000).

Farmers involved in participatory experimentation with the aim to increase crop yield and to obtain knowledge about novel technologies and practices (Fig. 1.1: middle sphere); researchers involved in the project with the primary objective to assess effectiveness (Fig. 1.1: outer sphere). BoARD-staff, field assistants and translators were involved too, but had only modest influence on the process.

Central in the research project were the four research cycles and the process in which both farmers and scientists were involved (Fig. 1.1: inner sphere). For the farmers these cycles constituted their main source of learning: not only the outcomes of the experiments themselves, leading to recommendations and higher yield, but also learning resulting from group interaction. Given this emphasis on functional (yield) and human-social (knowledge) outputs, outcomes of these research cycles were essential for answering my research questions relating to effectiveness, process and agronomic relationships.

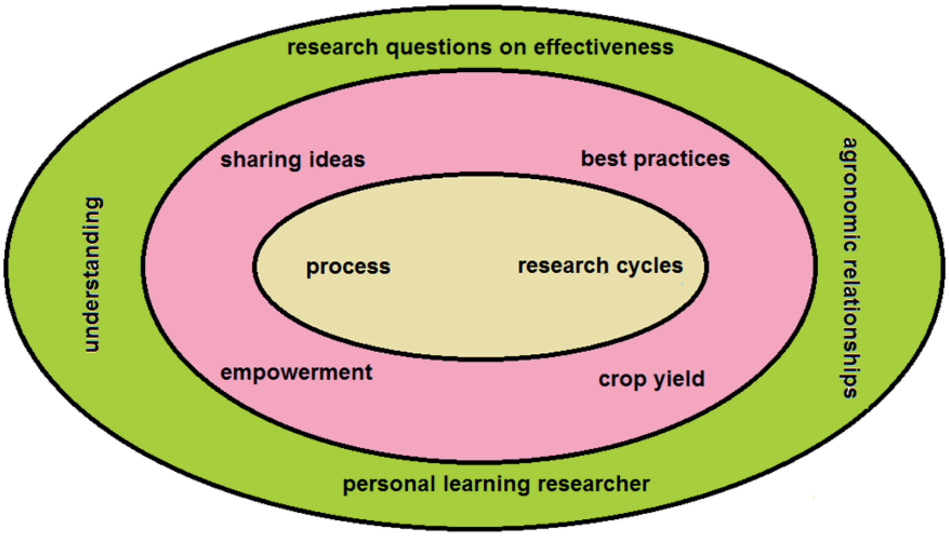


Figure 1.1: Set up of the research project. The three spheres respectively represent, inside-out: actual (participatory) experimentation, farmer concerns and researcher concerns.

To assess effectiveness in terms of relevancy of outcomes, functional and human-social change, I monitored experimental outcomes in the form of crop yield and farmer reported learning throughout the project.

To characterize and understand the process, roles and responsibilities of farmers and researchers, the actual process and farmers' involvement in it were monitored systematically through individual surveys and participant observation. Besides farmers' learning also personal learning of researchers took place which constituted of, for example, dealing with challenges relating to effective facilitation of the farmer groups. Although such learning was an important outcome of my involvement in participatory experimentation, it is not discussed in this thesis.

To explore relationships between experimental outcomes and agronomic factors different agro-ecological data were collected, such as for example, rainfall, soil nutrient content and amounts and composition of compost and manure used in the experiments. More specific details of different methods used are provided the experimental chapters (no 2-7) of this thesis.

1.7 Points of departure

Participatory experimentation (PE) processes ideally follow research cycles with specific phases (i.e. problem identification, design of research, data collection and evaluation). In each of these phases choices are made that determine the further course of the research. An essential pre-condition in my research project was farmers having a full mandate in each of these phases.

A well-defined protocol for my research was difficult to develop beforehand and most likely even more difficult to materialize; the same holds true for a set of well-defined variables to be measured. The actual process was open and moved around a few central themes: on-farm, experiential cycle, group-based and group discussion. Therefore, I chose an iterative approach to support my exploration using the following points of departure:

(1) A **long-term involvement** in PE was envisaged. In line with the recommendations of Guijt (2008), Misiko (2009) and Misiko et al. (2011), I wanted to involve farmers for at least four years and I took the time span from 2008-2014 to monitor both technical as well as social achievements.

(2) **Farmers involved as a group** since group work was considered very important in the context of participatory experimentation (Pretty, 1995; Tumbo et al., 2011; Yami, 2016).

(3) **Responsibilities were delegated** as much as possible to the farmers. Therefore, farmers were given the space to involve fully in the experimentation, not only by evaluating field performance, but also by having a full mandate for main steps in the research cycle (see for example, Arévalo and Ljung (2006), de Souza et al. (2012), Giller et al. (2008), Musvoto et al. (2015), Nederlof et al. (2004) and Ramisch (2014)). Maximum control over experimentation (analysis, design) was delegated to the farmers to avoid bias between groups due to our inputs (see also points 4 and 5 below). This extreme position was required to make our evaluation more meaningful and can be referred to as "*collegial*" (Biggs, 1989) or "*interactive participation*" (Pretty, 1995).

(4) Scientists involved in participatory experimentation primarily **concentrated on facilitation** of the process. Obtaining scientifically rigorous data in experiments was not the main objective. In the trade-off between scientific rigor and involvement (Okali et al., 1994), the latter was prioritized.

(5) Farmers' **dependency on scientist input and facilitation** substantially became less in the course of their involvement in participatory experimentation (Arévalo and Ljung, 2006).

(6) **Impact of local context** was assessed by including different sites (in total 16 sites distributed over four locations) to address the (potential) impact of context variability.

(7) **Incentives** for farmers other than those based on interaction and learning from participatory experimentation were deliberately reduced to a minimum (Islam et al., 2011).

(8) A **control group** of farmers ("non-participants") was used for assessing change resulting from involvement. This control group and all participating farmers were interviewed at the start and at the end of the process.

(9) From the start off and throughout the process **systematic monitoring** of participating farmers through interviews and observations took place.

1.8 Crop productivity in the context of Tigray

In Ethiopia, as in many other sub-Saharan countries, agricultural productivity is low. Production is clearly not meeting national demands, in the years 2007-2009 about 10 % of the total cereal consumption was imported whereas, at the same time, 43 % of the population was undernourished and agricultural GDP (Gross Domestic Product) was about 100 dollar per capita. Some improvement was achieved in the period 2011-2013 with agricultural GDP increasing to 110 dollar per capita (FAO, 2014). Progress with respect to undernourishment was substantial: for the period 2014-2016 this was reduced to 32% (CSA, 2016).

Recently an increase of agricultural production in Ethiopia has been achieved by increasing the production per unit of land combined with expanding the area of land under cultivation. For cereals, the main staple food, acreage roughly increased from 7.0 million to 10.0 million ha in the years 2003-2015; at the same time yields for wheat (*Triticum spp.*) increased from 1469 to 2535 kg/ha, for *teff* (*Eragrostis tef*) from 843 to 1560 kg/ha and for maize (*Zea mays*) from 1860 to 3387 kg/ha (CSA, 2004, 2016). This increase is necessary for Ethiopia, as for many other SSA-countries, to keep pace with the growing population (Worldbank, 2007).

Agricultural production in Tigray mainly takes place in mixed farming systems that focus on subsistence crops in combination with livestock production (Abegaz, 2005). In Tigray, as well as in the other Ethiopian highlands, expansion of cultivated area resulted in severe land degradation due to erosion and shorter fallow periods (Corbeels et al., 2000; Teklewold et al., 2013). This ongoing degradation had enormous economic and ecological impacts on the communities in the affected regions (Haileslassie et al., 2005). For Tigray cereal production figures were reported ranging from 2279 kg/ha for maize, 1875 kg/ha for wheat to 1343 kg/ha for *teff* in 2013 (CSA, 2014). Reported yields for 2015 were somewhat lower: respectively 2202, 1712 and 1166 kg/ha for maize, wheat and *teff* respectively (CSA, 2016), demonstrating the variable nature of crop production in the context of Tigray. Yields achieved on farmer fields are often much lower: Vancampenhout et al. (2006) found for *hanfets* (a local mixture of barley (*Hordeum vulgare*) and wheat) about 600 kg/ha in 2002, while Tsegay (2012) observed a *teff* yield of about 850 kg/ha on unfertilised plots. The scope for increasing actual yield for rainfed wheat (on average 1.4 tons/ha) in Tigray is about 3.2 tons/ha (GYGA, 2016).

Reasons for low crop yields in most of the northern Ethiopian Highlands are often related to unreliability and variability of rainfall in combination with problems like hail, soil erosion, poor soil fertility, pests, diseases and a low management level (Hengsdijk et al., 2005). Specifically, the low nutrient status of soils is considered to limit increase of crop yield (Stroosnijder, 2003). In northern Ethiopia food security has been an important issue for a prolonged period. Famine is not only historical but still part of collective memory. Together with international donors the government of Ethiopia has implemented a "*safety net"* programme based on Food-For-Work and direct aid (Coll-Black et al., 2012; Devereux et al., 2008; Sabates-Wheeler and Devereux, 2010). The importance of this "safety net" programme for rural livelihoods is high. For example, in the year 2011 in Tigray over 40% of the rural households were dependent on this system of food aid for one or more months a year (data provided by BoARD).

Given the high population pressure and lack of possibilities to expand cropping area the only way to improve local food security is by reaching higher crop yield (Holden and Shiferaw, 2004; Nyssen et al., 2004). Abate et al. (2011) indicated that attempts to improve the local situation failed because many farmers hesitated, due to uncertainties related to different factors constraining productivity, to implement innovations and approaches that could increase agricultural productivity. In addition, farmers, in general, are risk averse (Holden and Shiferaw, 2004). Currently, the main development focus of extension workers and NGOs in the Ethiopian highlands is to prevent ongoing land degradation related to soil erosion, for example, by area closures (Yami et al., 2013), terracing and conservation agriculture (Kassie et al., 2009; Nyssen et al., 2011).

1.9 The study area

The study area, Tigray, is located in northern Ethiopia and bordered by Eritrea and northern Sudan (Fig. 1.2). Four locations (*woredas*) were selected in central and eastern Tigray: Weri-Leki, Dogua Tembien, Hawzen and Ahforom. Like many other parts of Ethiopia these can be considered highlands, with altitudes ranging from 1950 to over 2600m above sea level. The landscape consists of sedimentary rocks, basalt flows and volcanic relicts in the form of isolated mountains. Apart from some relatively flat plateaux developed on sedimentary rocks, the landscape is in most places strongly dissected due to incision and underlying fault structures. Important parent materials in the area are basalt (tertiary) and mesozoic sediments like shale, sandstone and limestone (Gebreyohannes et al., 2010; Van de Wauw et al., 2008). The main soil types found are Cambisols, Luvisols, Vertisols and Leptosols (FAO-IUSS, 2006). Consequently, the study area is very diverse with respect to biophysical context.

Farming systems, however, are relatively similar and differences mainly relate to cultivation of specific crops depending on local climate (Frankl et al., 2013). Mean annual maximum temperature ranges from 23 to 27 ^{o}C (Gebrehiwot and Van der Veen, 2013). A major part of the northern highlands suffers from a lack of moisture: in this part of Tigray average annual precipitation ranges between 500 and 750 mm and is determined by altitude and orography. Most of Tigray is considered semi-arid dryland (Nyssen et al., 2004). Rainfall is distributed over two rainy seasons: a short rainy season (*belg*) starting in February and continuing till May and a long rainy season (*meher*) starting in June and continuing till the end of August. Occasionally both seasons merge, which allows the cultivation of crops like Sorghum (*Sorghum bicolor*), which require a longer growing season. Organic matter content of most soils is low and soil nutrient content mainly depends on parent material (Murphy, 1959).

Figure 1.2: Location of the study area and the involved locations (*woredas*) in Tigray, northern Ethiopia (dots refer to administrative centres of the *woredas*, triangles to the experimental sites involved).

1.10 Thesis outline

In this thesis involvement of farmer groups in joint experimentation stood central. The five main research questions (section 1.5) associated with this involvement resulted in a series of more specific questions which were discussed in the experimental chapters of this thesis. Question no 4 required much attention: the ambition to understand the process and its determinants raised several additional questions which were basically connected with the different phases of the experimentation process (problem analysis, design, actual experimentation, evaluation). Below, I will relate the chapters with the research question(s) addressed specifically and the associated experimental phase:

In chapter 2, I aimed at contrasting methods for constraint identification (question no 4: problem analysis phase). For that purpose I compared different methods to identify crop productivity constraints. This was done by a review of methodologies and a case study on three specific methods in the context of Tigray. My halting point was the interface between real-life problems and constraints identified by using different methods.

One specific method, Focus Group Discussion, is considered more in detail in chapter 3. Qualitative data were quantified and used to identify constraints considered relevant by local farmers (question no 4: problem analysis phase). In doing so I halted at the identification of specific problems that served as an input for farmer experimentation.

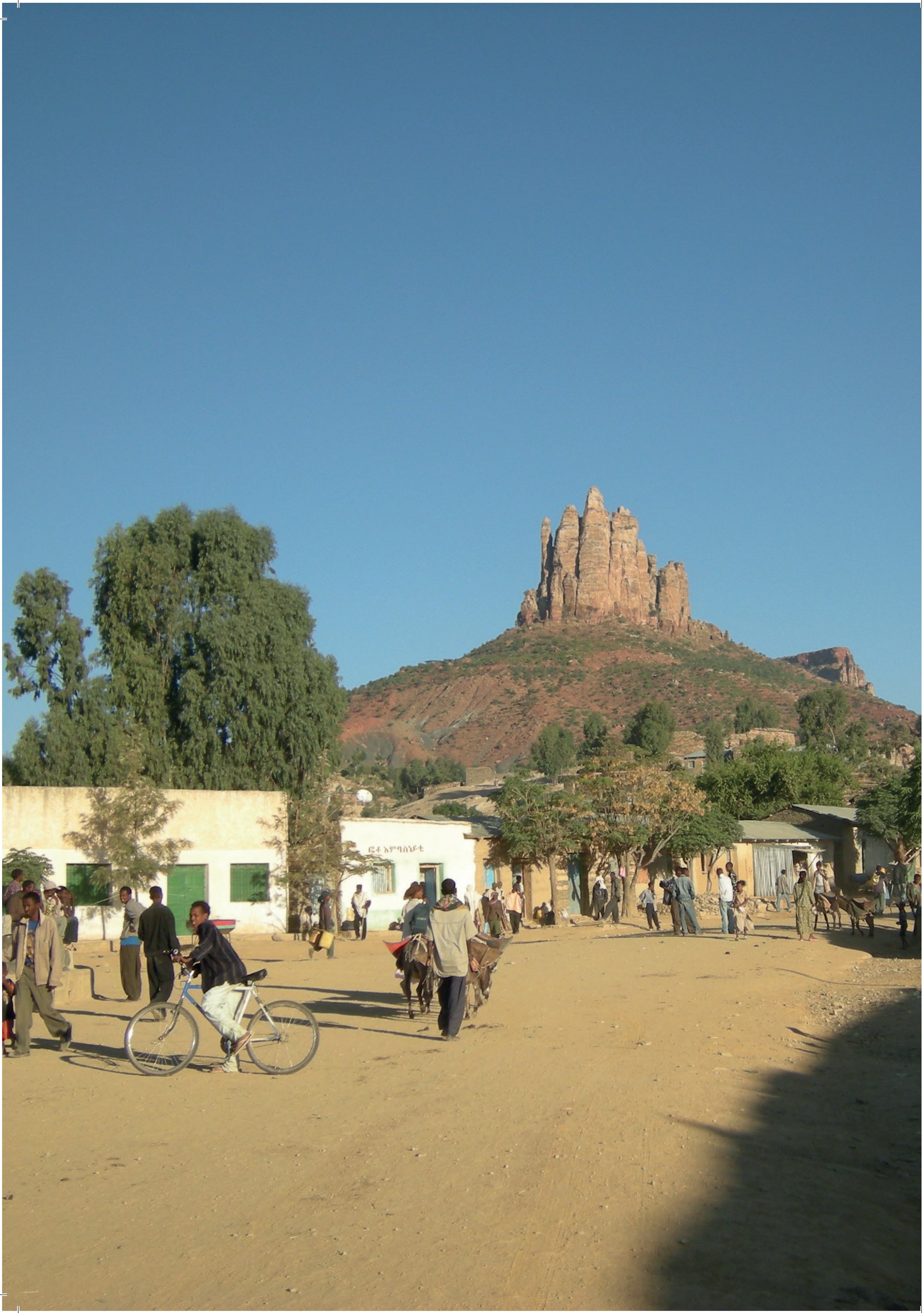
The technical outcomes of the experimentation are presented in chapter 4. The focus is on crop yield and responses of the different treatments. In addition, the correlation between outcome variability of on-farm experiments and local environmental factors (question no 5: relationships) was determined using multiple linear regression.

The experimental lay-out and how farmers, over the four years of their involvement, arrived at their actual designs and what research strategies were pursued is dealt with in chapter 5 (question no 4: design phase).

The impact of perspective on interpretation and implementation of experimental outcomes is discussed in chapter 6 (question no 4: evaluation phase). Different perspectives were used to interpret experimental outcomes in relation to sustainability. In doing so I focused on the interface between experimentation and learning.

In a specific chapter on learning (no 7), I considered the complex process of learning and change. Important questions were if involvement of farmers in participatory experimentation resulted in (farmer) learning and increased performance of their agricultural system (questions no 1, 2 and 3: contextual relevancy, functional and human-social aspects). A series of interviews involving participants and a control group in all phases of the research was used to generate such insights.

Finally in chapter 8 a synthesis of this research project is presented in which I answered my research questions and stepped out of the experimental cycles and moved up to a meta-level in order to reflect on process aspects. Here I also discussed the potential contribution of participatory experimentation to intervention work in the context of rural development and possibilities for further scaling.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2 Comparison of methods to identify crop productivity constraints in developing countries. A review

Based on: Kraaijvanger, R., Sonneveld, M., Almekinders, C., Veldkamp, T., 2015. Comparison of methods to identify crop productivity constraints in developing countries. A review. Agronomy for Sustainable Development 35, 625-637.

Abstract

Selecting a method for identifying actual crop productivity constraints is an important step for triggering innovation processes. Applied methods can be diverse and although such methods have consequences for the design of intervention strategies, documented comparisons between various methods are scarce. Different variables can be used to characterize these methods. To typify them, we used two of these variables in a heuristic model: control over de research process and represented opinion. Here, we review 16 published papers that present outcomes of different methods to identify productivity constraints. The major findings are the following: (1) variation in methods was wide; (2) applying the heuristic model resulted in three main clusters of methods: farmer-control/farmer-opinion, scientist-control/scientist-opinion and scientist-control/farmer-opinion; (3) these clusters were scale level dependent. As a follow up, we compared in a case study three different methods, representative for the three main clusters of the heuristic model, in order to assess their congruency. These methods (focus group discussion, individual surveys and contextual data collection) were applied in four localities in Tigray, Northern Ethiopia. We found that congruency between the methods, as indicated by Spearman-ρ correlations, was not significant. In addition, we found that outcomes of individual surveys and contextual data collection were both correlated ($R > 0.70$) among the different locations. No such correlation was found using focus group discussion. Both findings indicated that for a specific location different methods yielded different constraints, and that variability between the locations was not reflected by using individual surveys and contextual data collection. Combined the review and case study demonstrated that process control and represented opinion had a manifest impact on generated outcomes. Because outcomes of productivity constraints assessments are methodology dependent, researchers are recommended to justify a priori their choice of method using the presented heuristic model.

2.1 Introduction

In rural, subsistence-based farming communities, crop productivity plays an essential role in livelihood development. In order to achieve sustainable food-secure livelihoods, increasing crop productivity is usually considered an essential first step (Tittonell and Giller, 2013). In many cases, this justified the promotion of high input technologies, for example, in the form of Green Revolution style packages of new varieties, fertilizer application and pest and weed control measures (Denning et al., 2009; Dethier and Effenberger, 2012).

Despite numerous past and present attempts, the adoption rate and impact of such improved technologies has generally been limited in the marginal areas (Chambers and Jiggins, 1987a; Kolavalli and Kerr, 2002; Longhurst and Lipton, 1989). The reasons for these failures are not always clear but might be partly related to a limited understanding of the real world constraints that farmers face in their attempts to maintain and improve their livelihoods.

These real world constraints are diverse and related to both biophysical and socioeconomic factors. Biophysical factors constraining crop productivity for farmers include, for example, the incidence of droughts, the incidence of soil erosion and a low nutrient status of their soils (Hengsdijk et al., 2005; Nyssen et al., 2004; Veldkamp et al., 2001b). Socioeconomic factors can be endogenous, such as household composition, economic capacity of involved farmers, skills and confidence in specific technologies; or exogenous, such as lack of extension support, inadequate supply of fertilizer and availability of credit.

Careful identification and exploration of the often manifold and interrelated constraints in complex livelihood settings is an essential first step in identifying relevant opportunities for increasing crop productivity (Fujisaka, 1989; Giller et al., 2011). Currently, constraint identification is often done with desktop modeling studies using crop growth simulation models (Van Ittersum et al., 2013). A typical product is the Global Yield Gap Atlas (GYGA, 2016), in which identified constraints are directly derived from model assumptions (e.g., radiation, water, and nutrients) instead of real world analysis. Our review will not include these model derived methods.

Methods for identification of productivity constraints are diverse and range from collecting data on soil properties or crop development, conducting farming system research, experimentation, to tapping traditional knowledge and involving farmers through interviews or group discussions. Many of these methods are mono-disciplinary and do not include socioeconomic complexity of rural households. Others, however, pay more attention to local context and farmer perception.

An example to illustrate the importance of considering the local context is the case of using weeds to feed livestock, as is common practice in the Ethiopian Highlands. In these land use systems, grazing areas are very limited. Weeds therefore are not considered waste products but seen as an essential forage source for livestock during the cropping season. In addition, the flowers of the weeds are valued as a source of nectar for bees. Weeding actually means harvesting cattle fodder, which is even washed to make it more palatable (Fig. 2.1). Recommending these farmers to use herbicides, to reduce the labor requirements for weeding, therefore meets considerable resistance. Adoption of this technology is, for obvious reasons, not very likely. In many cases, however, "experts" fail to see this logic and blame the farmers to be traditional or even backward.

In this paper, 16 published papers dealing with systematic identification of crop productivity constraints were reviewed. Context and objectives were specific for each paper. Using a heuristic model, we classified these papers into different methodological clusters. In addition, fitting within these clusters, three prototype methods for constraint identification were compared within the specific context of low input systems in Tigray, Northern Ethiopia. The heuristic model and comparison were used to discuss in what way the selection of specific methods influences the outcomes of the constraint identification and consequently the selection of opportunities based on it.

Figure 2.1: Complexity of farming systems in central Tigray: young boy washing weeds in a small stream to feed livestock during the cropping season when grazing areas are scarce.

2.2 Heuristic model and prototype methods

Important variables to characterize different methods for the identification of crop productivity constraints are scale level, represented opinion, involvement of stakeholders, responsibility for analysis, used sources of information, and procedural control. Focusing on two variables that are important for the outcomes of constraint identification, i.e. (1) the control over the identification process and (2) the presented opinion/knowledge used to identify the constraints, and considering the two main actors, i.e., the scientist and the farmer, a heuristic model can be developed with four categories (see also Fig. 2.2): "scientist control - scientist opinion", "scientist control - farmer opinion", "farmer control - farmer opinion" and "farmer control - scientist opinion".

Between these categories intergrades are possible, but for each category also prototype methods can be indicated. Relevant within our context are, for example:

- Contextual Data Collection (CDC): scientist control-scientist opinion
- Individual survey (IS) : scientist control-farmer opinion
- Focus group discussion (FGD) : farmer control-farmer opinion
- Consultancy : farmer control-scientist opinion

With CDC, we refer to data collected by scientists covering a wide range of data from secondary sources: from exact data on soil properties to census data on family composition. Choices are made *a priori* and reflect the reference framework of involved scientists. Scale levels are mostly aggregated since especially data on detailed scales are often not available. Although contextual data collection appears an objective method at first sight, it is the scientist who takes decisions on the selection of variables, the threshold-levels, the sources of data used and the final analysis. A bias is easily introduced as a consequence of the orientation of the study, the expertise of the involved scientists and the availability of data.

Individual surveys (IS) use knowledge and opinions of individual farmers on specific topics through semi-structured or structured interviews. Respondents are direct sources of information, but scientists control the procedure, formulate the questions, and select respondents for interviews. In addition, suggestion from the side of the interviewer and expectations from the side of the respondent may introduce distortion of the collected information. If collected data are quantitative, statistical analysis is relatively straightforward. Qualitative outcomes, however, require more efforts. Outcomes can be superficial or in-depth depending on the procedure, type of questions, and the respondents involved. IS can be applied to generate outcomes at different scale levels, ranging from farm to supra-national level.

In the case of FGD, the initial focus of the discussion is usually controlled by the researcher. The extent and direction of the dialogue and discussion taking place varies strongly, depending on the objective of the researcher. However, FGD is usually considered to give space for free group interactions like negotiation and cross-comparisons. These are supposed to result into a shared and balanced opinion. Data are considered to be rich and innovative (Trenkner and Achterberg, 1991). Initially, FGDs were applied in the field of marketing, evaluation, and product development (Kidd and Parshall, 2000). Currently, it has also become a more popular tool in participatory development processes with four examples in our review.

The position of the facilitator, who supports the FGD-process, is delicate and a possible source of bias. Depending on the objective, participants can be stakeholders directly involved (like farmers) or experts on specific topics. Participants are often pre-selected for the purpose of stratification. Interpretation of the data is difficult, due to its qualitative nature (Trenkner and Achterberg, 1991). In some cases, analysis and interpretation of FGD-outcomes is partly carried out by the participants involved, like, for example, in the case of fuzzy cognitive mapping (Kok, 2009).

With consultancy, we refer to data collection by experts who are assigned to the task by stakeholders. In the case of "farmer control – scientist opinion", it would be farmers who take the initiative for the constraint identification, but delegate the task to the scientist. The scientist develops the data collection and analysis framework, resulting in a representation of his or her opinion. This type of consultancy is mostly found in more developed settings with high inputs and very specific requests, like, for example, in large scale commercial farms and plantations.

2.3 Different use of methodologies: a review

2.3.1 Presenting outcomes

Using common literature data-bases (Scopus, Web of Science and Google-scholar), we selected 16 published papers in which crop productivity constraints were identified. To identify and select relevant papers, we used keywords like “crop productivity”, “constraint” and “identification”. Our focus was on “tropical” and “sub-tropical” environments. The selected papers demonstrated a wide variety in objectives, scale level, methodology, and outcomes.

Fujisaka et al. (1994a), for example, discussed the outcomes of diagnostic surveys concerning the identification of research priorities for the rice-wheat cropping system in India and Nepal. Surveys were conducted by multidisciplinary teams of scientists. Opinions of both farmers, derived from individual surveys, and scientists were included. Analysis in a later stage, to indicate research priorities, was done by scientists and partly based on farmer accounts. Main problems identified were related to crop management, nutrient depletion and the incidence of pests and diseases.

Kimiti et al. (2007) used participatory discussions in Kenya to ensure involvement of farmers in the identification of soil fertility constraints. Farmers identified soil erosion as a main factor and perceived poor yields and crop development as an indicator for this decline in fertility. In an additional participatory session, opportunities to deal with such a decline were proposed.

In contrast to such participatory methods, Braimoh et al. (2004) relied on fuzzy logic to determine land suitability for maize production in Northern Ghana on basis of soil data resulting from 120 sample points. Expert knowledge was used to select variables and the cutoff points required in the applied mathematical procedures. Soil fertility, expressed by effective cation exchange capacity (ECEC), organic carbon, and clay content, was identified as a major constraint.

To characterize the methods applied, we used scale level, methodology, control over the process, represented opinion, identified constraints and the identified (related) opportunities as main concerns (Table 2.1).

Table 2.1: Characterization of reviewed cases.

No	Author	Location	Scale	Methodology	Process control	Represented opinion	Type of identified constraint	Type of identified opportunity
1	Affholder et al. (2003)	Brazil	regional	model analysis	scientist	scientist	agronomic-general	
2	Ajayi (2007)	Southern Africa	supra-national	individual surveys	scientist	farmer	agro-socio-economic-general	
3	Ayenor et al. (2004)	Ghana	commu-nity	participatory methods	farmer	farmer	agronomic-context specific	agronomic-context specific
4	Braimoh et al. (2004)	Ghana	regional	fuzzy analysis	scientist	scientist	agronomic-general	
5	Drechsel et al. (2001)	sub Saharan Africa	supra-national	literature	scientist	scientist	socioeconomic-general	
6	Fujisaka et al, (1994a)	South Asia	supra-national	individual surveys/expert knowledge	scientist	farmer	agronomic-general	agronomic-general
7	Govindaraj et al. (2010)	India	commu-nity	individual surveys	scientist	farmer	agronomic-context specific	
8	Kimiti et al. (2007)	Kenya	commu-nity	participatory methods	farmer	farmer	agronomic-context specific	agronomic-context specific

Table 2.1 continued: Characterization of reviewed cases.

No	Author	Location	Scale	Methodology	Process control	Represented opinion	Type of identified constraint	Type of identified opportunity
9	Lançon et al. (2007)	West Africa	supra-national	expert knowledge	scientist	scientist	agronomic-general	agronomic-general
10	Mowo et al. (2006)	Tanzania	commu-nity	participatory methods	farmer	farmer	agronomic-general	
11	Odera et al. (2007)	Kenya	commu-nity	participatory methods	farmer	farmer	agronomic-context specific	agronomic-context specific
12	Ryan (2008)	Syria	regional	literature	scientist	scientist	agronomic-general	agronomic-general
13	Uzunlu et al. (1999)	Turkey	regional	individual surveys	scientist	farmer	agronomic-formal	agronomic-general
14	Zhang et al. (2004)	China	regional	fuzzy analysis	scientist	scientist	agronomic-general	
15	Bekele and Drake (2003)	Ethiopia	commu-nity	individual surveys	scientist	farmer	agro-socio-economic-general	agro-socio-economic-general
16	Waddington et al. (2010)	Africa, Asia	supra-national	expert knowledge	scientist	scientist	agro-socio-economic-general	

The scales at which the reviewed methods identified constraints varied from supra-national (Waddington et al., 2010; Lançon et al., 2007; Fujisaka et al., 1994a; Ajayi, 2007), regional (Affholder et al., 2003; Braimoh et al., 2004; Zhang et al., 2004)) to community level (Govindaraj et al., 2010; Kimiti et al., 2007; Odera et al., 2007). The reviewed methods covered a wide range and included, for example, science-based expert knowledge (Lançon et al., 2007), evaluation models (Affholder et al., 2003; Braimoh et al., 2004; Zhang et al., 2004), literature-based data (Drechsel et al., 2001; Ryan, 2008), interviews (Ajayi, 2007; Govindaraj et al., 2010; Uzunlu et al., 1999), and farmer-based participatory methods (Ayenor et al., 2004; Kimiti et al., 2007; Mowo et al., 2006; Odera et al., 2007).

Control over the process of data collection and interpretation differed considerably between the applied methods. This control ranged from equally distributed between scientist and farmer to more periphery positions. For example, in the case of Affholder et al. (2003), Lançon et al. (2007), Ryan (2008) and Zhang et al. (2004) control was fully by the involved scientific team, whereas in the case of Ayenor et al. (2004), Kimiti et al. (2007), Mowo et al. (2006) and Odera et al. (2007) control in essential phases of the process was also by the farmer-stakeholders involved. Only in the case of Ayenor et al. (2004), farmers were also fully involved in the final phase, in which the research agenda was determined; for all other cases outcomes mostly served as inputs for next stages in the process.

Methodology also determined represented opinion, which again ranged between both periphery positions. Scientist-centered opinions were found with Affholder et al. (2003), Drechsel et al. (2001) and Ryan (2008), whereas Ajayi (2007), Kimiti et al. (2007) and Odera et al. (2007) represented farmer-centered opinions. Identified constraints either had a general scientific character (Affholder et al., 2003; Fujisaka et al., 1994a; Mowo et al., 2006) or related to a context specific grassroots level (Ayenor et al., 2004; Lançon et al., 2007; Kimiti et al., 2007; Govindaraj et al., 2010) .

The identified constraints in most cases had an agronomic character and only in the case of Drechsel et al. (2001), Waddington et al. (2010), and to some extend Bekele (2006) and Ajayi (2007) socioeconomic elements were included.

Constraints were mostly having a general character, being in most cases only at community level context specific (Ayenor et al., 2004; Govindaraj et al., 2010).

Some of the reviewed publications also included agronomic opportunities connected to the constraints identified. The character of these constraints was either more general, like, for example, in Fujisaka et al. (1994a), Ryan (2008) and Zhang et al. (2004) or more context specific like in Ayenor et al. (2004) and Kimiti et al. (2007).

2.3.2 Summarizing: using the heuristic model

The reviewed publications were, on the basis of attributed qualitative (ordinal) weight of responsibility for respectively control and opinion, and stratified according to scale level, plotted in the heuristic opinion-control model (Fig. 2.2). Zhang et al. (2004), for example, used in China on a regional scale expert knowledge, and at the same time fully controlled the process. In the heuristic model this paper therefore was plotted in the lower left section. Kimiti et al. (2007), at the other hand, used in Kenya at community level farmers opinions, and made them to some extent responsible for the process. In the model this paper was plotted in the upper right section. In the model also the four prototype methods were indicated.

The reviewed cases belonged to three main clusters: the specific combination of farmer control and scientist opinion was not found among the publications considered. When considering scale level, the categorization showed that the method which combined farmers opinion and process control, which presumably represented a high degree of participation, generated results that related to the community level. The combination of farmer opinion and scientist control also generated regional and supra-national level outcomes. In the category of scientist control and scientist opinion, only higher scale level outcomes were generated.

The indication that different methods yielded different types of results, motivated our case study in which we compared three different methods within the same area. These methods were selected in such a way that they served as a prototype for categories fitting within our heuristic model.

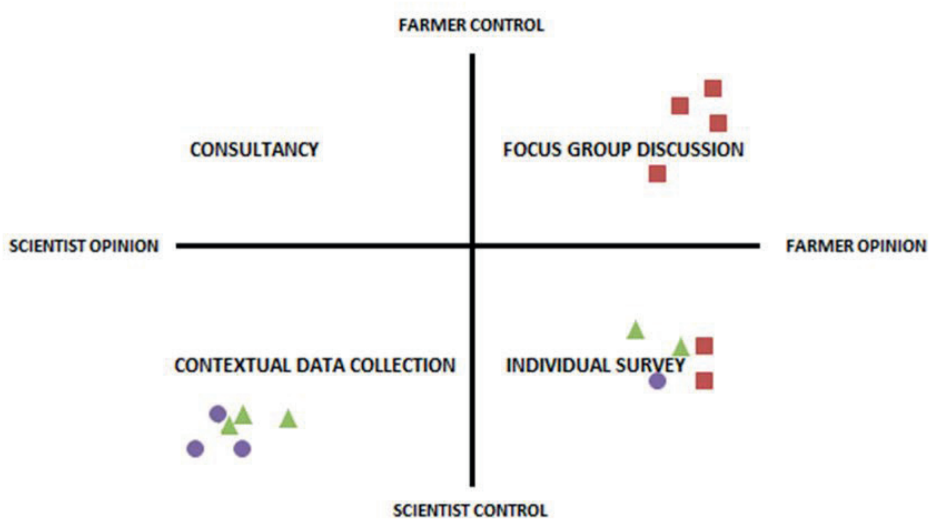


Figure 2.2: The reviewed publications with outcomes at different scale levels and prototype methods plotted in a heuristic model (■= community, ▲= regional, ● = supra-national).

2.4 Comparing different methods for the identification of productivity constraints in Tigray

2.4.1 Background and context

We aimed to compare three relevant prototype methods for the identification of productivity constraints. These prototype methods, Focus Group Discussion (FGD), Individual Surveys (IS), and Contextual Data Collection (CDC), fitted within the frame work of a research project on farmer experimentation. We applied these three methods in four *woredas* (medium scale administrative units) in the central part of Tigray: Werie-Leke, Hawzen, Ahforom and Dogua Tembien (Fig. 1.2). In this study these *woredas* were indicated by the names or abbreviations of their respective administrative centers: Edaga Arbi (EA), Hawzen (HW), Inticho (IN) and Hagere Selam (HS).

In each *woreda*, we selected three or four sub-locations, *tabias* (small scale administrative units), that provided focus group participants as well as interview respondents. All data were collected from November 2008 till March 2009, except the outcomes of soil analysis which became available in 2012. The outcomes of the different methods were compared and assessed with respect to congruency.

2.4.2 Study area description

In our study area, the central part of Tigray, smallholder subsistence farmers using limited external inputs represent the main part of the agricultural population. Farm size does, in general, not exceed 0.75-1.0 ha, and crop productivity is low. Vancampenhout et al. (2007) reported for cereals yield-levels of around 700 kg/ha. The low production has put the traditional farming system under pressure and resulted, in combination with the limited environmental resilience, in food insecurity, depleted fields, and degraded lands. In the central part of the region, an estimated 40% of the rural population structurally depended on food aid, despite attempts to improve productivity by introducing novel technologies.

In the study area, altitude varies between 1900 up to 2600 m. Rainfall depends on altitude and orography and is erratic and highly variable (Haileslassie et al., 2007; Nyssen et al., 2005). Annual precipitation ranges from 522 mm for HW to 683 mm for HS (Gebrehiwot and Van der Veen, 2013) and is distributed over a short rainy period (March and April) and a long rainy period (May till August). Annual mean temperature also depends on altitude and ranges between 15 ^{0}C and 21.5 ^{0}C (Araya et al., 2010).

Most farmers in the study area practice mixed farming. Cattle and small ruminants are grazing depending on the availability of suitable areas. To provide food for the household, different cereals and pulses are grown in a cropping system based on frequent ploughing by oxen. Wheat, barley and *teff* are grown in the long rainy season. Maize, sorghum and finger millet are planted in March and in most cases only will be productive if both rainy seasons overlap.

In some cases, farmers have access to water for irrigation: in HW and HS small hand dug wells and ponds are found, in EA micro-dams with command areas of around 80 ha are present, and in IN diversion structures and motor-pumps are used to extract water from natural streams.

Next to the agro-ecological differences, the selected *woredas* varied with respect to intervention history. Between 1975 and 1990, EA was located in a war-zone and exposure to development activities was very limited. After 2000, in especially HW and HS, NGOs were implementing multiple development activities, in IN the local Bureau of Agriculture and Rural Development (BoARD) has been very actively promoting novel technologies to increase crop productivity.

2.4.3 The three prototype methods

2.4.3.1 Focus group discussion

In each *woreda* development agents provided names of farmers that were potentially interested to participate in workshops dealing with the issue of crop productivity. Only one out of about 80 approached farmers declined the invitation. We conducted four workshops, one in each *woreda*, with about 20 participating farmers in each workshop. In each workshop, which lasted one full day, farmers formed four *cushet* (neighbourhood)-based groups. These groups were responsible for identifying and prioritizing issues related to crop productivity. In each workshop we co-operated with the same (female) moderator.

To allow a proper evaluation within the framework of our research, we took an extreme position with respect to conducting FGD. Process-related interaction in the FGD, as provided by the moderator, was limited to explaining the topic of discussion and reporting its outcomes. We refrained from giving any comments relating to the crop productivity issues mentioned. At the same time we did not allow BoARD-staff to be present during the discussions to prevent influence of external opinions.

Outcomes of the workshops were so-called mind maps (Peterson and Snyder, 1998). To allow comparison between the four locations, these mind maps were translated into spider diagrams using a quantification procedure based on categorization of raised issues following a set of major concerns (Kraaijvanger et al., 2016a). The categories were either constraint or opportunity categories. In this paper, we only considered the constraint categories: (1) conservative management; (2) agronomic factors; (3) location specific issues; (4) land related issues; (5) demographic factors; (6) economic factors.

In our comparison we used the final outcome of this quantification procedure, the so-called *"relative perceived impact"*. This index combined the aspect of frequency, by which issues were mentioned and the aspect of weight attributed by the participants to issues within a specific category (for details, see Kraaijvanger et al. (2016a)).

2.4.3.2 Individual survey

In each *woreda*, 21 individual surveys on livelihood aspects were conducted with farmers living in the same *cushets* that provided the FGD-groups. The selection of the respondent-farmers was random, using administrative lists of these *cushets*. All interviews were held using the same (female) interpreter that also involved in the FGDs.

The individual surveys consisted of structured open questions which yielded a wide range of data on major social, economic and agronomic issues. In this comparison, we only used data from questions on crop productivity constraints. Responses from farmers were subjected to the same categorization as in the FGD-analysis. To accommodate all raised issues, the category "others" was included. IS-outcomes used in our comparison were calculated as percentage of a specific category in relation to the total of issues raised (Kraaijvanger, 2013).

2.4.3.3 Contextual data collection

CDC for the four *woredas* covered a set of agro-ecological and socioeconomic topics that we considered relevant in relation to agricultural productivity. Census data like farm-size, household-size, and livestock-number were collected from BoARD-offices at *tabia*-level and averaged to *woreda*-level. Composite soil samples were taken at representative fields in each of the involved *tabias* and analyzed for main soil properties. Meteorological data were collected at *woreda*-level. From the resulting dataset (Kraaijvanger, 2013), we selected rainfall, N-total, number of livestock, farm-size, and household-size.

These variables were converted into five constraint variables matching those used in the other methods applied as much as possible: rainfall deficit, rainfall variability, nutrient deficit, land shortage, and relative asset base. To allow comparison, we expressed these variables as percentages of assumed maxima. For this conversion we used the following procedures:

Rainfall deficit: Mean rainfall in the period ranging from February till October, was determined for a series of 6-15 years. In analogy with the concept of agro-climatic zoning (Araya et al., 2010; FAO, 1978), we related mean rainfall to potential evapotranspiration to obtain an indication for growth potential. Based on an average evapotranspiration of 6 mm/day (Doorenbos and Kassam, 1979), and a growing period of 100 days we assumed a total potential evapotranspiration of around 600 mm. The complement of the relation between mean rainfall and assumed evapotranspiration resulted in *rainfall deficit*:

$$100 - \frac{\text{observed mean rainfall} \times 100}{600} = \textit{rainfall deficit}$$

Rainfall variability: Next to the mean, as used in the case of rainfall deficit, also standard deviation, was taken into consideration to obtain an indication for rainfall variability:

$$100 - \left(\frac{\text{standard deviation} \times 100}{\text{mean rainfall}}\right) = \textit{rainfall variability}$$

Nutrient deficit: Soil organic matter and especially the nitrogen contained in it were considered essential in assessing soil nutrient status. We therefore related N-total, expressed in mg/kg, to an assumed reference level of 2000 mg/kg for medium nitrogen availability (Landon, 1991) and used its complement as an indication for the *nutrient deficit*:

$$100 - \left(\frac{\text{N-total} \times 100}{2000}\right) = \textit{nutrient deficit}$$

Lack of assets: Livestock is often considered a main indicator for wealth in smallholder mixed farming systems (Zingore et al., 2007). To estimate the relative resource basis we calculated the number of tropical livestock units (TLU) according to Abegaz et al. (2007). This was referenced to an assumed local maximum of 6.0

TLU, which stood for the number of livestock of the "richest" farmers in the study area. The obtained relative resource basis was converted into an indicator relating to *lack of assets* by taking its complement:

$$100 - \left(\frac{\text{TLU} \times 100}{6.0}\right) = \textit{lack of assets}$$

Land shortage: For smallholder subsistence farmers scarcity of land basically refers to a lacking capacity to support household needs. In analogy with Hadgu (2008), we therefore calculated an indicator for land shortage based on household size, farm size, estimated caloric production, and estimated caloric requirement. We assumed, based on an average cereal yield of 1200 kg/ha with an average energy of 15 MJ/kg (Norman et al., 1995), a caloric produce of one ha of land of 18 GJ. Additionally, a daily energy requirement of 8 MJ per household-member was calculated based on Werner et al. (2001). By including the farm size, and the number of household members the ratio (as a %) between produced and required food was calculated, and converted into an indicator for *land shortage* by taking its complement:

$$100 - \left(\frac{\text{acreage} \times 18000 \times 100}{(\text{household size} \times 8 \times 365)}\right) = \textit{land shortage}$$

2.4.4 Assessment of congruency

Congruency of the used methods was assessed by paring related categories, as shown in Table 2.2, for each combination of methods (FGD-IS, FGD-CDC, and IS-CDC). Ranks for the outcomes of the methods were attributed according to the following procedure: 1=lowest, 2=in between, and 3=highest. Attributed ordinal rankings for these categories were tested for correlation using Spearman-ρ.
The same procedure was applied to determine correlation between the four sites with respect to specific categories for each of the methods.

A high correlation between two methods implies their congruency, for example when for both methods a specific category scored in a specific *woreda* the same rank. High correlation between the *woredas*, under the assumption them to be different, however, suggests outcomes to be pre-determined by methodology.

This is the case when for example a specific constraint category in all four *woredas* for a specific method scored the same rank. Low correlation between the *woredas* due to diverse identified constraints, at the other hand might reflect, again under the assumption of contextual diversity, a more context-sensitive methodology. An example of this is when a constraint category scored in the four *woredas* all possible ranks (1, 2 and 3) for a specific method.

Table 2.2: Overview of constraint categories as covered by Focus Group Discussion, Individual Surveys and Contextual Data Collection. Combinations selected to assess their congruency are shaded.

Focus Group Discussion	Individual Survey	Contextual Data Collection
Conservative management	Conservative management	
Agronomic factors	Agronomic factors	
Economic factors	Economic factors	Lack of assets
Demographic factors	Demographic factors	Land shortage
Land related issues	Land related issues	Nutrient deficit
Location specific issues	Location specific issues	Rainfall variability
	Other	
		Rainfall deficit

2.4.5 Outcomes of methods applied

For each location, the outcomes of the methods were presented as percentages in radial diagrams to allow comparison (Table 2.3). For EA, location specific issues were most frequently mentioned as productivity constraint in FGD. In contrast, economic and demographic factors were most frequently mentioned in IS, and nutrient deficiency became apparent in CDC. For HW, location specific issues were mentioned as a main productivity constraint. IS and CDC pointed, in the case of HW, to economic factors and nutrient deficit respectively as main constraints for productivity.

Table 2.3: Relative score's (as % of an assumed maximum) for different constraint categories as identified by Focus Group Discussion, Individual Surveys and Contextual Data Collection for four different locations in central Tigray.

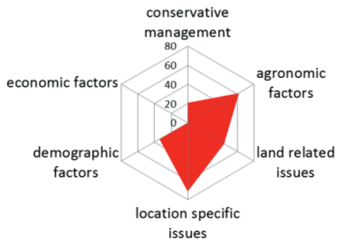
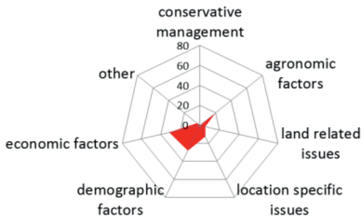
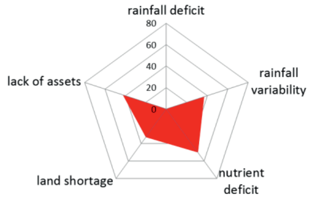
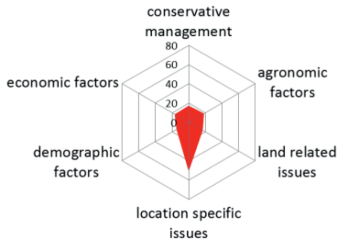
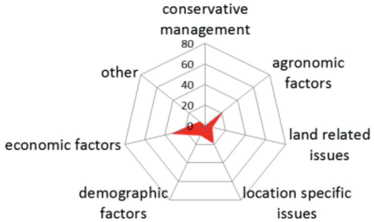
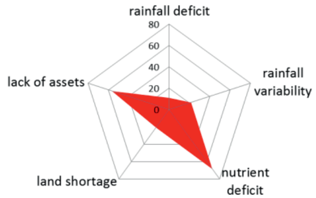
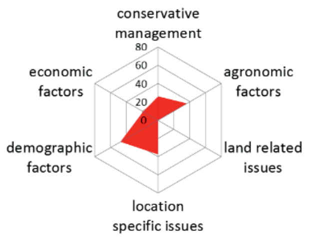
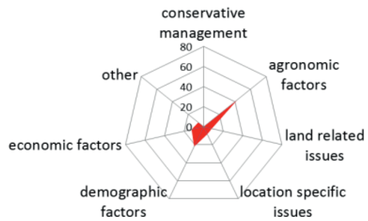
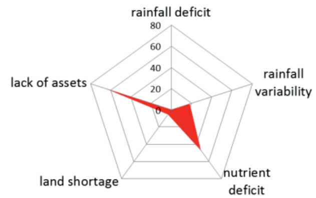
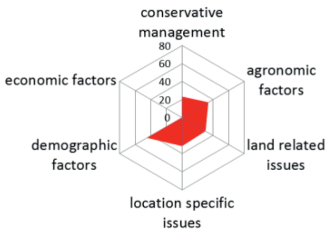
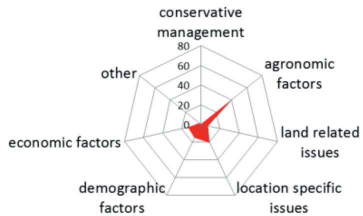
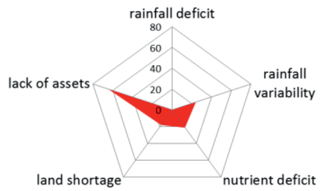
	Focus Group Discussion	Individual Surveys	Contextual Data Collection
Edaga Arbi			
Hawzen			

Table 2.3 continued: Relative score's (as % of an assumed maximum) for different constraint categories as identified by Focus Group Discussion, Individual Surveys and Contextual Data Collection for four different locations in central Tigray.

<table>
<tr><th></th><th>Focus Group Discussion</th><th>Individual Surveys</th><th>Contextual Data Collection</th></tr>
<tr><td>Inticho</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Hagere Selam</td><td>
</td><td>
</td><td>
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</table>

For both IN and HS, demographic factors were dominant in FGD. However, demographic factors and land shortage did not come out as relevant issues using IS and CDC. Using IS in both IN and HS showed that agronomic factors were mentioned as a main factor. Lack of assets was identified as a main constraint using CDC. Similarities in identified constraints for the locations involved were especially observed when comparing diagrams resulting from the use of IS and CDC.

2.4.6 Comparability of outcomes

Table 2.4: Spearman-ρ correlations between different combinations of methods and between different locations.

	Evaluated method(s)	Correlation coefficient
Congruency	Focus Group Discussion Contextual Data Collection	0.255
	Focus Group Discussion Individual Surveys	-0.312
	Individual Surveys Contextual Data Collection	0.125
Outcome variability	Focus Group Discussion	0.454*
	Individual Surveys	0.711*
	Contextual Data Collection	0.875*

** = significant p<0.05*

Spearman-ρ correlations between the outcomes of the compared methods were only low (Table 2.4). Correlations between the methods were positive, except for the combination FGD-IS (constraints), which showed a negative correlation. Congruency between the compared methods therefore was not very likely.

A relatively high Spearman-ρ correlation ($R > 0.70$) was demonstrated between the four locations with respect to the outcomes when using IS and CDC. Applying FGD to identify constraints resulted in a relatively low correlation ($R < 0.50$) between the *woredas*.

2.5 Discussion

2.5.1 Review of selected papers

The review of 16 papers yielded a wide variation in methods and procedures which were used for the identification of constraints in relation to crop productivity. This variation was manifest in for example the use of specific data sources and different responsibilities for procedures and interpretation. Uniformity in methodology at this end was absent. Scale level and objectives to a large extent determined the selection of a specific methodology.

In most cases, quite general constraints were identified. This contrasted with the multiple, context and interdependent constraints that are usually considered relevant for successful development-oriented interventions. In our review, only community level methods yielded the identification of context relevant constraints. This was not surprising, but at the same time questioned the energy invested in in the identification of often obvious and general constraints. Exemplary in this were the constraints identified in a supra-national yield gap analysis (Waddington et al., 2010), indicating an almost equal responsibility for each of the constraints identified.

When considering the reviewed participatory methods, we observed that these were quite diverse with respect to the responsibilities delegated to the farmers. For being participatory, ideally some degree of control by the farmers involved is considered mandatory (Pretty, 1995). Researchers, however, often seem afraid to delegate this control. Govindaraj et al. (2010), for example, claimed the application of participatory techniques but actually the influence of farmers was restricted to providing information, which fits better with individual surveys.

2.5.2 Comparison of different methods within the same case study

The three methods we compared yielded considerably different types and priorities of crop productivity constraints. This implied they are not 1-1 exchangeable.
FGD generated a contextually differentiated multi-focused set of constraints. Only location specific issues could be considered a common denominator for all *woredas*. This seemed consistent the with character of FGD in which group interaction and negotiation are likely to address complexity and context. The

importance of group interactions within FGD was also found by Asfaw et al. (2012): they concluded that group outcomes were more diverse and most likely more relevant as compared to data resulting from individual surveys.

The IS-outcomes tended to provide a single-focused picture which primarily related to short-term concerns of individual farmers. Agronomic and economic factors appeared prioritized and mentioning these issues might have been directed by expectations in relation to obtaining support, for example, in the form of credit or supply of farm-inputs. Critical reflection was often lacking, resulting in somewhat superficial outcomes.

The quality of CDC as a method depends, in general, heavily on quality of the data used and the availability of appropriate thresholds. In our case, we rated the reliability of the rainfall data as doubtful, this might have resulted in a too optimistic interpretation.

The outcomes for CDC were very similar for the different locations, despite their biophysical variability. They indicated as main constraints that farmers lack assets and that soils were nutrient deficient. This might have been a consequence of the pre-selection of variables and threshold levels. Including more detailed variables and data appears a logical option; in that case, however, CDC tends to become a farming system analysis.

Correlation between the outcomes of different *woredas* was high in the case of IS and CDC. For FGD correlation was much lower. Based on the assumption of different agro-ecological and socioeconomic contexts of the involved *woredas* (Kraaijvanger, 2013), this suggested differences in context sensitivity for the different applied methods, with FGD seeming the most context sensitive method.

2.5.3 Epistemological foundations

The aspects of process control and represented opinion, the foundations of our heuristic model, allowed us to differentiate between the reviewed cases. This resulted in three main categories.

Control over the identification process is extremely important since many pre-analytical choices are involved in this process. Clear examples are the selection of variables and data sources, and attributed responsibilities for interpretation. Such decisions at the same time will determine the content and reliability of the generated outcomes (Röling et al., 2004). Only questions raised will be answered and only variables selected will be considered.

With respect to represented opinion, it is important to realize that scientists and farmers use different sources of knowledge, which is generated with different procedures and in different contexts (Dea and Scoones, 2003; Hoffmann et al., 2007; Maat, 2011). Different represented opinions therefore likely result in different outcomes.

Both process control and represented opinion are clearly essential elements of methods for constraint identification in the sense that they have a manifest impact on outcomes generated and their applicability. Researchers, therefore, should explicitly consider these methodological aspects and indicate beforehand who will be in control of the research and whose opinions will be represented. Being conscious of their specific position occupied within the opinion-control framework consequently will lead to more concern of researchers about the selection and epistemology of applied methodologies.

2.5.4 From identification of constraints to forwarding opportunities

On the basis of the outcomes of constraint identification processes in many cases opportunities will be forwarded to support intervention work. In development processes, however, not only an academic just identification of constraints, but especially the way how to deal with them in a practical setting counts.

To achieve adoption of forwarded opportunities by farmers requires an understanding of their preferences and motivations (Ajayi, 2007; Bekele, 2006; Knowler and Bradshaw, 2007). Forwarded technologies should fit in the existing livelihood systems and support the overall sustainability of farming systems (Bekele, 2006; Sumberg, 2005; Sumberg et al., 2003).

Successful novel technologies should not only be technological sound but also match with the complex socio-cultural setting in which smallholder farmers operate (Hailu, 2009; Sturdy et al., 2008). New technologies, in addition, need to match with available competence and capacity to allow smooth integration into existing livelihood systems. Such an integration likely will secure sustainable development (Altieri et al., 2012).

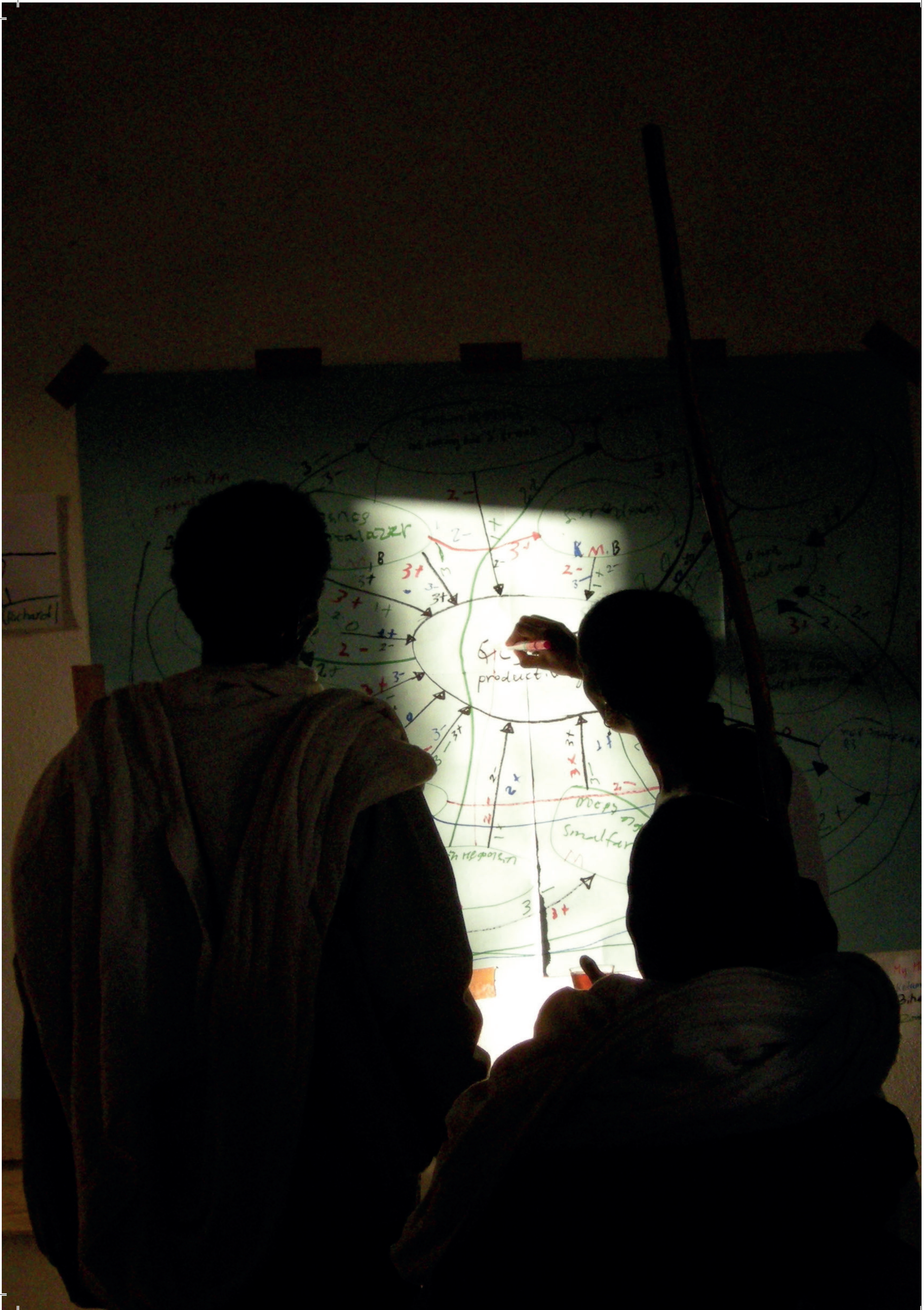
In arriving at such opportunities, it definitely matters *who* selects them from *which "basket full of options"* in the sense of Tittonell and Giller (2013). Considering this, the opinion-control framework also appears relevant with respect to processes aiming at the identification of opportunities.

2.6 Conclusion

The literature review demonstrated that for the different applied methods farmers and scientists held different positions with respect to process control and represented opinion. Comparison of associated prototype methods indicated that these were not congruent and as such not exchangeable. Major differences between the methods with respect to the constraints identified were found. These differences were related to methodological characteristics of the applied methods. Explicit and purposive labeling of methods for constraint identification with respect to process control and represented opinion consequently might lead to a more adequate selection, design and application of these methods.

Acknowledgements

We want to thank Hidat Mesfin for translating and assisting with interviews and focus group discussions.



3 Identifying crop productivity constraints and opportunities using Focus Group Discussions: A case study with farmers from Tigray

Based on: Kraaijvanger, R., Almekinders, C.J.M., Veldkamp, A., 2016a. Identifying crop productivity constraints and opportunities using focus group discussions: A case study with farmers from Tigray. NJAS - Wageningen Journal of Life Sciences 78, 139-151.

Abstract

Crop productivity in many places in sub Saharan Africa is low. This affects food security and rural livelihoods. Identification of constraints and opportunities is a first and essential step in development processes aiming at improving crop productivity. Macro- and mesolevel diagnostic methods frequently point to soil fertility and agronomic practices as major constraints. In Tigray, our study area in Northern Ethiopia, we applied focus group discussion in four locations to identify productivity constraints and opportunities. Outcomes in the form of mind maps were quantified to allow comparison between the locations. We found that, apart from some similarities, outcomes demonstrated much diversity. Location specific conditions and agronomic factors were considered main constraints by farmer groups in all locations. Soil fertility measures were considered a main opportunity. However, other categories of constraints and opportunities, like economic factors and irrigation, were diverse for the locations involved. Observed outcome variability was supported by descriptive biophysical and socioeconomic data. We concluded that superficial identification of constraints and opportunities neglected contextual diversity. Making such diversity visible is essential in understanding and addressing this complexity. Applying approaches like focus group discussion, therefore, offers important opportunities at grassroots level to give farmers a mandate and responsibility at early stages of development processes.

3.1 Introduction

3.1.1 Identification of crop productivity constraints

In sub Saharan Africa (SSA) a majority of the rural livelihoods depends on subsistence farming based on low external input systems. These systems face major challenges in relation to productivity, which is often low, and sustainability, which is in many cases questionable. Low productivity and lacking sustainability have a pronounced negative impact on development of involved livelihoods.

Tigray, in northern Ethiopia, is an example of an area with livelihoods based on such systems. Here, low crop productivity results in food insecurity and a high vulnerability (Kassie et al., 2009). In most households no surplus of food will be available and even during normal rainfall years around 40 % of the farm households structurally depends on food aid (data provided by BoARD). Food aid in such cases might have become part of the livelihood strategy of farmers, as was also described by Siyoum (2012) for other parts of Ethiopia.

Identification of crop productivity constraints and relevant opportunities is very important in order to design interventions aiming at improved agricultural productivity and, related to that, improved livelihoods. Constraints can be identified at different scale levels. At higher scale levels, for example, Tittonell and Giller (2013) indicated that for SSA nutrient deficiency is a major constraint and responsible for yield gaps. Also Waddington et al. (2010) identified nitrogen deficiency, together with limited access to fertilizers and seeds, weeds and diseases as important constraints for African Temperate Highlands. In line with this the Sasakawa Global-2000 program, which relied on addressing productivity constraints, forwarded a strategy based on the Green Revolution mantra of improved varieties and fertilizer application for Ethiopia in the 90's (Howard et al., 1999; Keeley and Scoones, 2000).

At lower scale level, an analysis based on descriptive data for Tigray revealed that, in contrast to our expectations, rainfall in the region seemed adequate enough to support crop production but that soil nitrogen level in most cases was low (Kraaijvanger, 2013). Farm management was observed to be traditional and only limited external inputs were used. This led to the assumption that limited availability of soil nitrogen and a low management level were important productivity constraints.

These are three examples of diagnosis that resulted in a predictable set of non-specific constraints, i.e. water, nutrients and management, having no relation with complexity at the local level. Arriving - based on the above constraints - at "*best fits*" for intervention (Giller et al., 2011), consequently, is challenging.

In addition, the diagnostic methods referred to above are criticized because they tend to ignore farmer knowledge and preferences, resulting in non-effective interventions and limited adoption of proposed technologies (Ajayi, 2007; Sumberg et al., 2003). In response to this lack of impact, participatory methods are advocated to generate data at grassroots level, to address livelihood complexity (Chambers and Jiggins, 1987a; Defoer et al., 1998; Pretty, 1995) and to achieve empowerment (Mayoux and Chambers, 2005). Participatory approaches, however, often yield qualitative insights which complicates analysis and reporting (Onwuegbuzie et al., 2009a; Trenkner and Achterberg, 1991).

Participatory approaches are assumed to be essential (Mayoux and Chambers, 2005; Sherman and Ford, 2014) in relation to achieving change. To assess the effectiveness of participatory approaches we developed a research project focusing specifically on participatory experimentation in the context of low external input agriculture. In relation to effectiveness we considered various technical and social outcomes (like recommended practices, novel agricultural management and empowerment). An important point of departure in our research project was to delegate as many responsibilities as possible to participating farmers in order to achieve a *collegial* type of participation (Biggs, 1989). Following such a mandate, farmers were to be involved in all phases of experimentation, including problem identification.

Participatory approaches are diverse and applicability of specific approaches depends on objective and context. Examples range from mapping and ranking exercises to developing calendars and diagrams, transect walks and role-plays (Mayoux and Chambers, 2005; Negash et al., 2006). Within the context of our research project in Tigray we used one of these approaches, focus group discussion (FGD), to identify crop production constraints.

FGD is a specific participatory method that combines the aspect of working in groups with that of groups being in control of the process (Kraaijvanger et al., 2015). By using FDG we aimed to arrive at insights relevant for the specific context of the groups involved as well as to achieve some degree of empowerment. In addition, FGDs allowed us to involve farmer groups as much as possible in all experimental phases.

3.1.2 Focus Group Discussion

In FGD a group of participants discusses specific issues. It is a popular method to collect relatively large volumes of information in a relatively short time. This information contains different forms of cognition expressed by the groups involved, like, for example, experiences, perceptions, insights and opinions.

In FGDs, opinions of individual participants are converted to a more or less shared group opinion. Process factors related to group interaction like negotiation, presence of networks, power relations, knowledge generation and learning processes (Shahvali and Zarafshani, 2002) are, next to cognition, essential components of a FGD. The associated group interaction is assumed to provide a certain level of content validity of the generated information (Kidd and Parshall, 2000).

Ideally, participants in FGDs control the discussion and collection of information (Kraaijvanger et al., 2015). In specific conditions this control can even be expanded to settings in which participants bear responsibility for the identification of the topics of the discussion and its final analysis and interpretation.

Analysis of FGD-outcomes is often a relatively arbitrary and time consuming exercise (Chioncel et al., 2003; Trenkner and Achterberg, 1991). These outcomes typically are "rich and innovative" (Trenkner and Achterberg, 1991); examples of outcomes are, next to transcripts, video-recordings and notes taken (Onwuegbuzie et al., 2009a), also physical products like "mind maps" and "rich pictures". Reporting, interpretation and use of outcomes in a more comparative way is often complicated. Analysis of outcomes by outsiders is difficult and its richness cannot always be exploited. The knowledge involved in such cases therefore may not always become fully explicit.

In general, documented experiences at lower scale levels, indicating how these outcomes are translated into priorities and related interventions are relatively limited. Examples can be found in the context of participatory plant breeding (e.g. Asfaw et al. (2012)). All in all, using FGD means embarking on open processes with valuable and rich outcomes that require careful analysis of outcomes to allow meaningful implementation in development context.

3.1.3 Research objectives

In this paper we used the results of FGDs to discuss its potential in relation to the design of interventions to support local people in their livelihoods. We analyzed a series of FGDs with farmers aiming at constraint and opportunity identification in four locations in Tigray. In addition, we described and discussed the systematic procedure we developed, allowing us to compare the four locations involved. In relation to this we identified the following objectives:

- Identifying which constraints and opportunities the farmers involved perceived and how these compared to the (macrolevel) outcomes of more general approaches.
- Reflecting on process and procedures involved in conducting and analyzing FGDs.

3.2. Material and methods

3.2.1 Study area

In Tigray four *woredas* (sub-regional administrative units) were involved: Werie-Leke, Hawzen, Ahforom and Dogua Tembien (Fig.1.2). In this study we used the names or abbreviations of their respective administrative centers to indicate them: Edaga Arbi (EA), Hawzen (HW), Inticho (IN) and Hagere Selam (HS).

Smallholder subsistence farmers, using limited external inputs represented the main part of the agricultural population. Farm size, in general, did not exceed 0.75-1.0 ha and, given the low yields obtained, many farmer households are food insecure. Altitude in the study area varied between 1900 and 2600 m above sea level. Rainfall depended on altitude and orography and was erratic and highly variable (Haileslassie et al., 2007; Nyssen et al., 2005).

The four *woredas* were selected based on a brief assessment of their typical characteristics (Table 3.1): Edaga Arbi representing a somewhat isolated area and as such typical for many remote locations in Tigray, Hawzen representing a typical drought-prone area with much activity of non-governmental organizations (NGOs), Inticho representing a more developed area with abundant small-scale irrigation activities present and a good access to markets and finally Hagere Selam, which is a relatively cool highland area with high rainfall and much NGO-activity.

The selected *woredas* showed distinct differences with respect to development intervention history. Between 1975 and 1990, Edaga Arbi was located in a war-zone and exposure to development activities by NGOs and extension, consequently, was very limited. After 2000, especially in Hawzen and Hagere Selam, NGOs were strongly involved with development activities; in Inticho the local Bureau of Agriculture and Rural Development (BoARD) actively promoted novel technologies to increase crop productivity.

Table 3.1: Relative estimated importance of specific concerns for the four different study locations. (Estimations by the first author, on the basis of field observations and interviews; BoARD = Bureau of Agriculture and Rural Development; EA = Edaga Arbi; HW = Hawzen; IN = Inticho; HS = Hagere Selam).

Concern	**Estimated importance**
	Low--------------------------Medium--------------------------------High
NGO and BoARD activity	EA---HW--------------HS/IN
Irrigation	EA---HW/HS----------------IN
Fertility	HW--EA/IN--------HS
Drought	HW--------------EA----------------IN---------------------------------HS

At *woreda*-level BoARD is responsible for planning and organization of development activities and specialized experts deal with, for example, livestock or watershed management. *Woredas* are divided into *tabias* (villages) which again are divided into *cushets* (neighbourhoods), the lowest administrative level. Development activities are implemented at *tabia*-level, for example, in the form of Farmer Training Centers (FTCs). The offices of development agents are located in these FTCs and often also demonstration facilities and fields are present.

Descriptive data, based on individual surveys (n=21 for each location) in the involved *tabias,* demonstrated considerable differences between the locations with respect to holding size, livestock number, farm-family ratio and use of fertilizers (Table 3.2).

Table 3.2: Descriptive data of the four locations (TLU=Tropical Livestock Units, standard deviations between brackets, survey data are based on n=21 for each location).

Variable	**Location**			
	Edaga Arbi	**Hawzen**	**Inticho**	**Hagere Selam**
Farm size total* (ha)	1.04 (0.55)	0.89 (0.63)	0.68 (0.35)	0.83 (0.41)
Household size* (persons)	6.43 (1.96)	6.67 (2.15)	6.95 (1.88)	6.48 (2.16)
Farm-family-ratio* (total ha/person)	0.16 (0.07)	0.13 (0.09)	0.1 (0.05)	0.14 (0.10)
Hiring-index* (% hired /total land)	39.21 (24.44)	17.98 (22.08)	23.59 (24.56)	21.67 (23.94)
Fertilizer use-index (kg/ha)	90.66 (61.18)	102.15 (60.02)	135.37 (96.91)	50.48 (46.54)
TLU* total/farm	3.31 (2.09)	2.86 (2.35)	3.09 (1.26)	2.44 (1.73)
Average rainfall (mm/year)**	742	522	742	683
Mean minimum temperature (^{0}C) **	12	10	12	11
Mean maximum temperature (^{0}C) **	27	27	27	23
Parent material***	Shale, basalt	Shale, sandstone	Basalt	Basalt, shale, sandstone, limestone
Altitude range (m) ***	1950-2200	1950-2100	1959-2100	2300-2600
Soil types***	Cambisols, Vertisols, Luvisols	Cambisols, Vertisols	Cambisols, Luvisols	Vertisols, Cambisols, Phaezems

* Census data based on individual surveys, conducted 2009 in the *tabias* involved (see Kraaijvanger (2015b)).
** Adapted from Gebrehiwot and Van der Veen (2013); rainfall for 1991-2008, temperature for 2008.
*** Biophysical data: observations by the first author.

3.2.2 Procedure FGD

Four FGD-workshops with farmers were conducted from November 2008 to February 2009, one in each *woreda* selected. The topic of these workshops was crop productivity and our objective was to explore farmers' perceptions of related constraints (problems) and opportunities (solutions). Crop productivity was selected as a central topic since our research on effectiveness of participatory experimentation was conducted in a low yield and low external input context. The identification of constraints and opportunities by the farmers involved in participatory experimentation was an essential first step in the participatory process envisaged.

The selection of participants was based on using key-informants (see Rocheleau (1994)), i.e. FTC-staff at *tabia*-level, who supplied names of farmers that were: (1) assumed to be interested and willing to participate in a process of joint experimentation and (2) came from the same *cushet*. FTC-staff categorized these potential participants as active farmers that in many cases had been engaged before in research activities. In each of the *cushets* five farmers were approached personally to request their participation in the workshops.

In the FGDs cognitive inputs other than that of the participant-farmers, were avoided as much as possible. For example, we did not allow BoARD-staff to participate and restricted our personal involvement to process matters like facilitation and moderation. Our ambition was, in line with Pretty (1995), to delegate responsibilities as much as possible to the farmers.

Commitment of the farmers was high: only one out of about 80 farmers invited excused himself for medical reasons. A majority, about 75 %, of the farmers participating was illiterate. The workshops, all with the same female moderator, were held in meeting halls or offices of BoARD. In each of the workshops around 20 farmers participated in four *cushet*-based groups (each of about five farmers). FGD in our case can be considered an expert panel-FGD, farmers being extremely knowledgeable with respect to livelihood issues.

3.2.3 Construction of mind maps

In the workshops the moderator presented three central questions to the farmers, which were the basis for the construction of the final mind map (see also Pascual et al. (2016) and Peterson and Snyder (1998)):

1. What are important issues related to crop productivity ?
2. To what extent/degree do these issues have impact on crop productivity ?
3. How and to what degree are these issues related ?

These questions respectively related to identification, prioritization and addressing complexity. Each of these questions was dealt with in specific sessions, interrupted by tea and lunch breaks. In the first part of each session, the question concerned was discussed by the members of the *cushet*-based groups, in the second part of a session these groups contributed to the preparation of the "mindmap" (Fig. 3.1).

After informing participants on the context and objectives of the workshop the moderator explained the first central question. Farmers discussed this question in their group and a spokesman made notes on the outcomes. All four groups orally reported their findings through their spokesman and all issues that, according to them, related to crop productivity, were noted on a map. By using colours, it remained clear which group had contributed a specific issue. In case a group referred to an issue already mentioned by another group, their colour was added. In this way the map represented all identified issues for all four groups. At the same time, the outcomes presented were discussed among the participants and questions were raised. This session took about two hours.

In response to the second central question, the groups were requested to attach, using their colour, a weight to each of the issues on the map they considered relevant. They were allowed to use values from 1, 2 or 3, using + or – for respectively a positive or negative contribution to crop productivity. In case they did not consider an issue relevant they left it blanc. After the discussion in the groups again spokesmen of all four groups presented their findings and added, using their colour, numbers to the map. During this session, which again took about two hours, groups reacted also on issues raised by other groups.

Figure 3.1: Farmers from Inticho adding their findings to the map.

For the third central question, farmers were requested to discuss the relations between the issues on the map and the weight of these relations. In each workshop we used the same examples to highlight this specific question: (1) the (inter)relation between population and farm size and (2) the (feedback)relation between productivity and fallowing. After discussion in the groups issues present on the maps were connected by using arrows, and numbers were added by either the moderator or by a spokesmen, again using their group's color. In this part groups reacted on each other and asked, for example, for explanation. Also this session took around two hours.

After about six hours the workshop closed with the moderator explaining that the complex mind map needed to be analyzed and by looking forward to the next phases of the participatory experimentation process.

3.2.4 Quantification of FGD outcomes

The original FGD-procedure, in our case producing a qualitative-visual mind map, was extended with an additional step in which the initial outcomes were quantified. This quantification was meant to support analysis of outcomes (Onwuegbuzie et al., 2009b) and to make the mind maps more instrumental in comparing similarities and differences for the four locations. To develop this additional procedure we used an iterative stepwise process that converted the raised issues and their attributed weights into radial diagrams.

Step 1: Translating and organizing data

After conducting the workshop the issues on the mind maps were registered in a spreadsheet that included frequencies and attributed weights. In a few cases, notably in the case of Edaga Arbi, the primary outcomes of the workshop had to be slightly adapted since some misunderstanding with respect to the signs of the weights had occurred.

Step 2: Categorization

Categorization was the necessary next step since the number of issues was unexpectedly high, up to 40 issues for one workshop. In the four workshops together a total 106 different issues were identified by the farmers and recorded on the maps. Many issues overlapped or differed sometimes only in word choice and appeared to belong to a shared domain, i.e. category. Therefore, categories were defined around broad concerns like shortage of assets (economic factors), constraining pests (agronomic factors) or contra-productive management (conservative management). This process finally resulted in twelve categories that allowed complete and transparent accommodation of the raised issues with a sufficient level of detail, coherence and similarity. Categories were divided into two main groups: constraints (= problems) or opportunities (= solutions). There were six constraint categories: demographic factors, agronomic factors, economic factors, conservative management, location specific issues and land related issues. The six categories referring to opportunities were: good management, innovative management, irrigation, soil and water conservation-measures, soil fertility measures and external factors (Table 3.3).

The categorization allowed us to transform somewhat diffuse qualitative data into more structured information allowing further analysis. Due to this categorization, information ("richness") is likely to get lost and at the same time foci might have shifted due to generalization. We tried to compromise this trade-off by defining categories *ex post* that, in line with Chioncel et al. (2003), remained as close as possible to the issues that were forwarded by the participants, avoiding a merely academic perspective. For example, the application of fertilizers is supposed to boost productivity and, consequently, is an opportunity whereas its cost definitely is an economic constraint.

Step 3: Quantification

In the quantification procedure, frequencies of quotes (i.e. times of mentioning) for the issues within a category were used in combination with weights attributed. In this way not only the themes emerging from the discussion, but also the aspect of consensus (Onwuegbuzie et al., 2009b) and priority were included in our quantification. This finally resulted in what we called *relative perceived impact*. To arrive at this *relative perceived impact* we used, in analogy with indicators like citation-index, the concerns of both frequency and attributed weight. Two indices, respectively *consensus-index* and *priority-index*, were introduced to represent them.

Frequency aspects were covered by the level of consensus farmers demonstrated during the FGD-workshops. The *consensus-index* for a specific category was calculated by dividing the total number of quoted issues by the number of different identified issues in that category:

consensus-index = total quotes in a category / identified issues *(i)*

The maximum value for this *consensus index* of a category was four, in case all (four) groups quoted all identified issues.

The aspect of attributed weight was represented by defining the *priority-index*. To calculate this *priority-index* for a specific category we divided the (absolute) sum of all attributed weights in this category by number of times a weight was attributed by the groups:

$$\textit{priority-index} = \Sigma \textit{ attributed weights / times of grading} \qquad (ii)$$

The maximum value for this *priority-index* was three, in case all groups attributed the maximum weight of three.

Both aspects, *consensus-index* and *priority-index*, were combined in an indicator for the perceived impact of a specific category on crop productivity. For this purpose both indices were multiplied:

$$\textit{perceived impact} = \textit{consensus-index} \times \textit{priority-index} \qquad (iii)$$

To allow comparison of the *perceived impact* between the four locations, the maximum attainable value of the *perceived impact* was used. This *maximum perceived impact* depended on the number of groups that participated and was determined by taking the maximum for both indices. For Edaga Arbi, Hawzen and Inticho this maximum was 12, for Hagere Selam it was 9.

The *relative perceived impact* then was calculated as a percentage of the *maximum perceived impact*:

$$\textit{Relative perceived impact} = \textit{(perceived impact/ maximum)} \times \textit{100 \%} \qquad (iv)$$

Step 4: Visualization

Radial diagrams for constraint as well as opportunity categories for each of the locations were constructed to allow systematic comparison between the four locations.

Table 3.3: Twelve categories of constraint and opportunities with in total 106 accommodated issues raised by farmers in the four FGD-workshops (SWC = soil and water conservation).

Constraint category	**Mutual concern**	**Issues**
Conservative management	Contra-productive traditional management	wasting time, un-ability to construct well, no manure use, post-harvest losses, many cultural holidays, not taking care for trees, not growing many vegetables, using much food for celebrations, working without plan, not working hard, depending on governmental support, in proper use of credit, not adopting innovations practically, not using fertilizers, not using improved seeds, dated ploughing methods, not using compost, delayed ploughing, livestock destroying crops, incorrect method of sowing, not diverting flood to the land, incorrect use of fertilizer, not ploughing timely, incorrect ploughing method, not weeding, broadcast sowing, not using insecticides, delayed sowing, bad land management, not mixing fertilizer with manure
Agronomic factors	Constraining pests	weeds, *humodia* (a fungal disease), animal pests, caterpillars, Striga (a parasitic weed)
Land related issues	Relation with specific land qualities	absence of terraces, incidence of soil erosion, poor soil fertility , wet soil, ponding of the land
Location specific issues	General conditions	shortage of rain, natural disasters, fog, hail, delay of rains, absence of micro-dams, rain during harvest
Demographic factors	Shortage of land	small farm, absence of fallow, no crop rotation, high population pressure, absence of forest
Economic factors	Shortage of assets	absence of oxen, not having farm tools, expensive fertilizer

Table 3.3 continued: Twelve categories of constraint and opportunities with in total 106 accommodated issues raised by farmers in the four FGD-workshops (SWC = soil and water conservation).

Opportunity category	**Mutual concern**	**Issues**
Good management	Traditional management supporting productivity	matching crop with soil type, timely weeding, timely ploughing and sowing, taking care for the crops, ploughing often, not spending food for celebrations, timely farm management, terrace maintenance, proper time use, crop rotation
Innovative management	Management requiring inputs	using credit, using improved seeds, correct sowing method, proper use of insecticides, using drought resistant crops, using selected seeds, loosening soil for vegetables/fruits, growing cash crops, growing suitable improved crops, growing vegetables/fruits, family planning, using insecticide, using improved varieties, improved seeds, availability of vegetable seeds
Soil fertility measures	Improving nutrient status of soil	using fertilizer, using compost, correct use of manure and fertilizer, proper handling of manure and fertilizers, incorporating crop residues, using manure and compost, cheap fertilizer, correct use of fertilizer, correct use of compost
SWC-measures	Soil and water conservation	drainage of the land, green strips between the fields, terracing
Irrigation	Irrigation	dam construction, check dams, using ponds/wells, expanding irrigated land, construction of micro-dams, availability of plastic for ponds, using drip irrigation, flood diversion to the land, using diversion
External factors	No direct control by farmers	sufficient rain, peace, support development agents, resettlement of farmers

3.3 Results

3.3.1 Focus Group process

In the workshops interaction took place between farmers and moderator, between the farmers in a group and between groups. The first author concentrated on observation and reporting the process. In a few occasions he was involved in answering specific questions of participants, especially in case workshop questions were not clear for all participants and required additional explanation.

In general, farmers demonstrated an active participation, discussions in the groups were calm and all farmers seemed to speak up, although some more than others. They left each other sufficient room for discussion and they rarely interrupted each other. Interaction of participants in general was polite, respect- and meaningful. The involvement of the female participants in the discussions in some cases was limited, however, this was not because of purposive exclusion by male participants. The form chosen, discussion in small groups of farmers, fitted very well with the way farmers in Tigray traditionally discuss matters of importance.

Farmers who were responsible for reporting mostly had a central role in the discussion. Being often the only literate farmer in the group, this spokesman in most cases gave the oral and written presentation of outcomes. In only a few cases the moderator made a written report of the outcomes of the groups. Both the literate spokesman and the support provided by the moderator were essential in dealing with the issue of illiteracy of the majority of the participants.

In case a similar issue was already reported by another group, discussion took place about differences between specific issues raised. In some, but not all cases this resulted in merging of issues. Especially during this part farmers reacted on findings of other groups in the form of questions or supportive remarks. With respect to the second question, farmers were also allowed to attribute weights to the issues forwarded by the other groups, an opportunity they eagerly took and which further enriched the map.

The first question did not cause many difficulties. Sometimes it was not clear to the participants that they were allowed to mention "problems" as well as "solutions" related to crop productivity. The weighing exercise connected to the second question initially was not fully understood by all participants. Therefore, further explanation was provided either by other participants or by the moderator. The third question addressed relations between issues and was quite challenging for the participants. Since the number of issues on the map at that stage was very high, it was difficult for the participants to have a good overview. In addition, in most cases only few farmers actually could read the information presented on the map. Responses to this third question, therefore, were not very comprehensive and consequently were not included in our analysis.

In retrospect, especially the Edaga Arbi groups had difficulties with the exercises. Mentioning constraints did not pose any problem. However, mentioning opportunities and doing the weighing exercise was rather confusing to them. Fewer difficulties arose for them with indicating relations between issues. In the Hawzen workshop farmers considered the weighing exercise difficult but interacted very much during the presentations. The Inticho farmers worked in a concentrated way and seemed used to workshop settings. The farmers from Hagere Selam did not have many difficulties with the questions, they were attentive and very interested in the findings of other groups.

3.3.2 Mind maps and radial diagrams

The constructed mind maps of the four locations visually differed in number of indicated issues and relations between them (Fig. 3.2). For Edaga Arbi the number of identified (and different) issues was relatively low compared to the other locations; however, relations between issues were more pronounced.

The radial diagrams constructed showed differences between locations with respect to type and magnitude of perceived constraints and opportunities (Table 3.4). Edaga Arbi farmers perceived location specific issues as a main constraint category and considered soil fertility measures as a main opportunity. No other opportunities, except for innovative management, were indicated. Hawzen farmers perceived location specific issues as the most important constraint category but also indicated several constraint categories of minor importance.

Both Inticho and Hagere Selam demonstrated a somewhat balanced output for both constraints and opportunities. Economic factors were not mentioned in Edaga Arbi and Hagere Selam and were considered minor in Hawzen and Inticho. The attention for soil and water conservation was limited in all locations except Hagere Selam.

In the following phases of our research project we reported our findings to the farmers involved and to staff of BoARD and local NGOs and found these confirmed. In the course of their participation in the research, farmers included different research topics but focused throughout on the issue of soil fertility (Kraaijvanger and Veldkamp, 2017). In addition, we found that all groups stayed involved in the research project, which also pointed to relevancy perceived of the issues addressed (Kraaijvanger et al., 2016b).

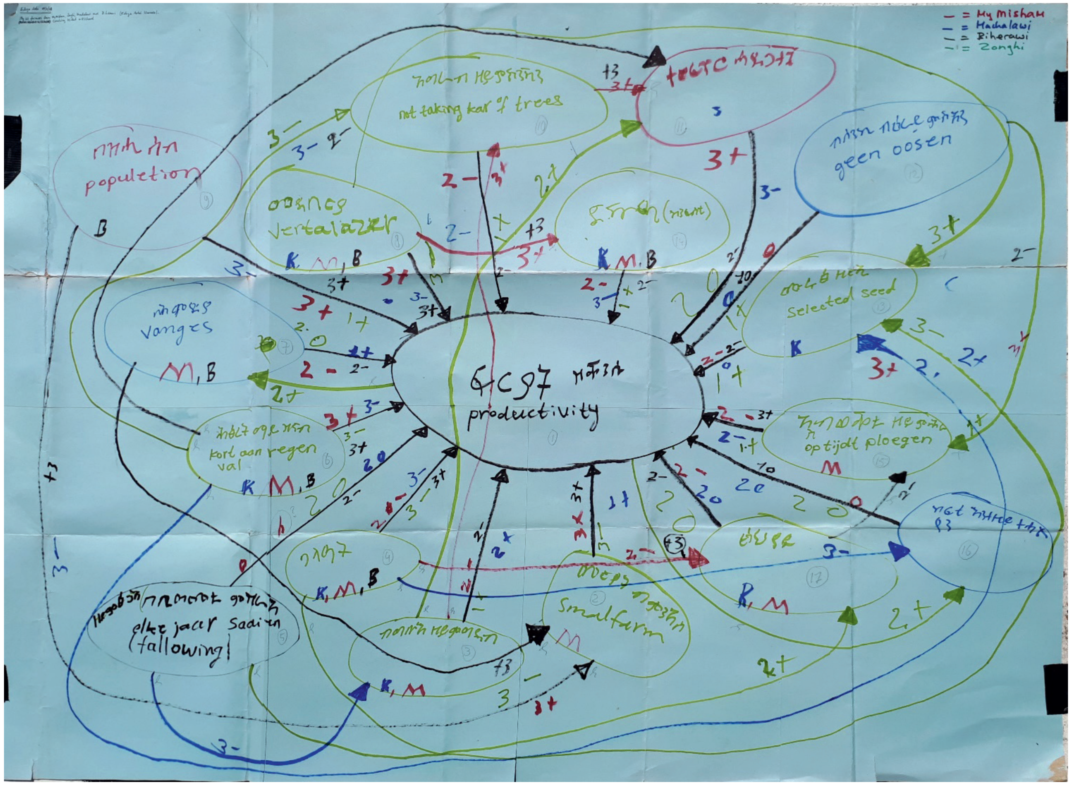


Figure 3.3a: Mind maps prepared in the workshops in the four locations: Edaga Arbi.

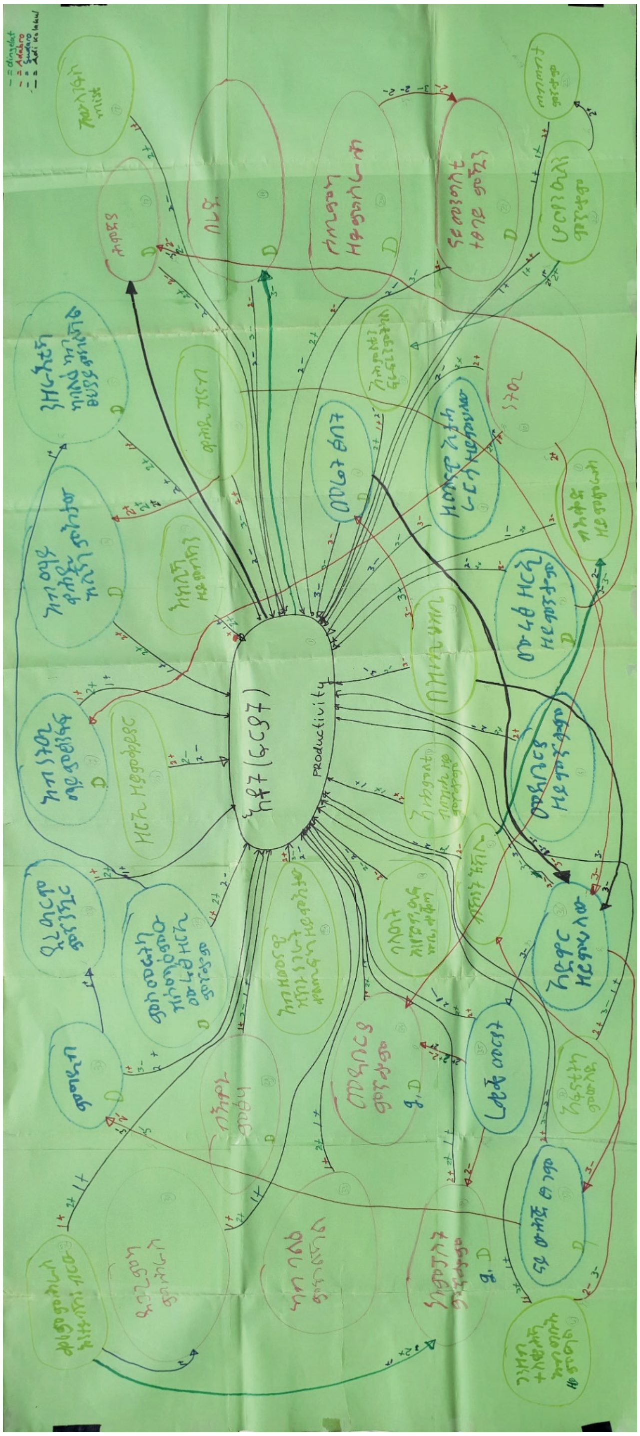


Figure 3.3b: Mind maps prepared in the workshops in the four locations: Hawzen.

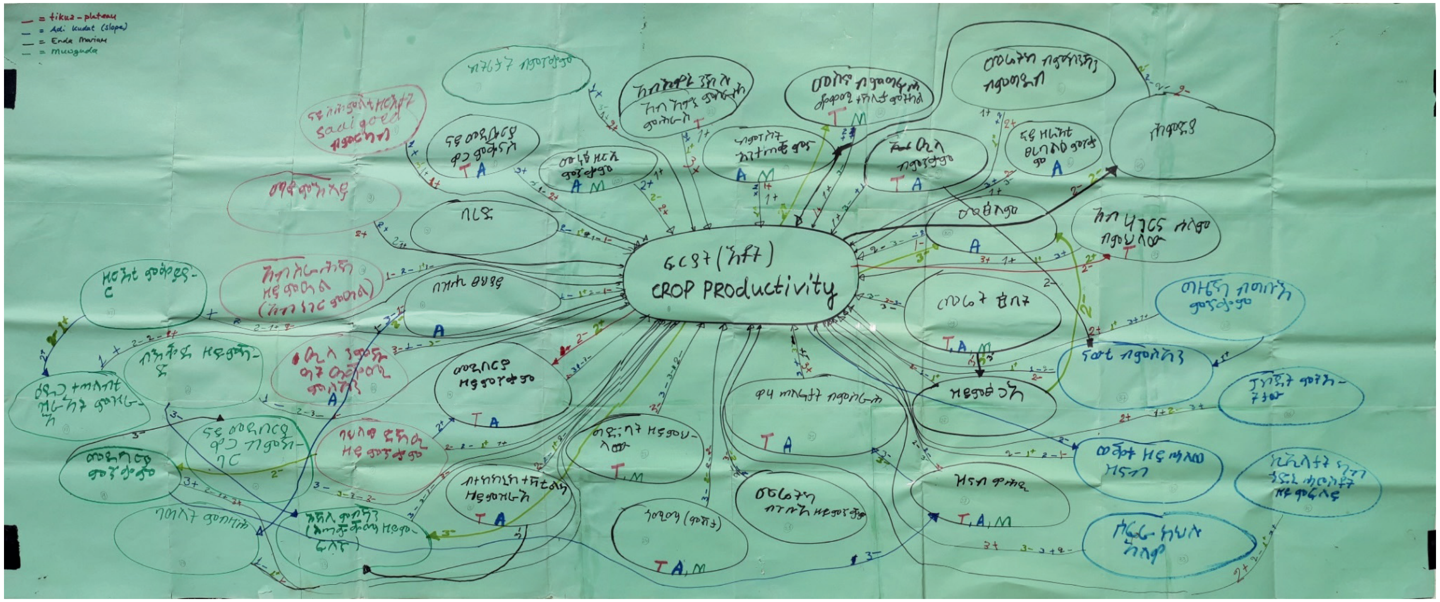


Figure 3.3c: Mind maps prepared in the workshops in the four locations: Inticho.

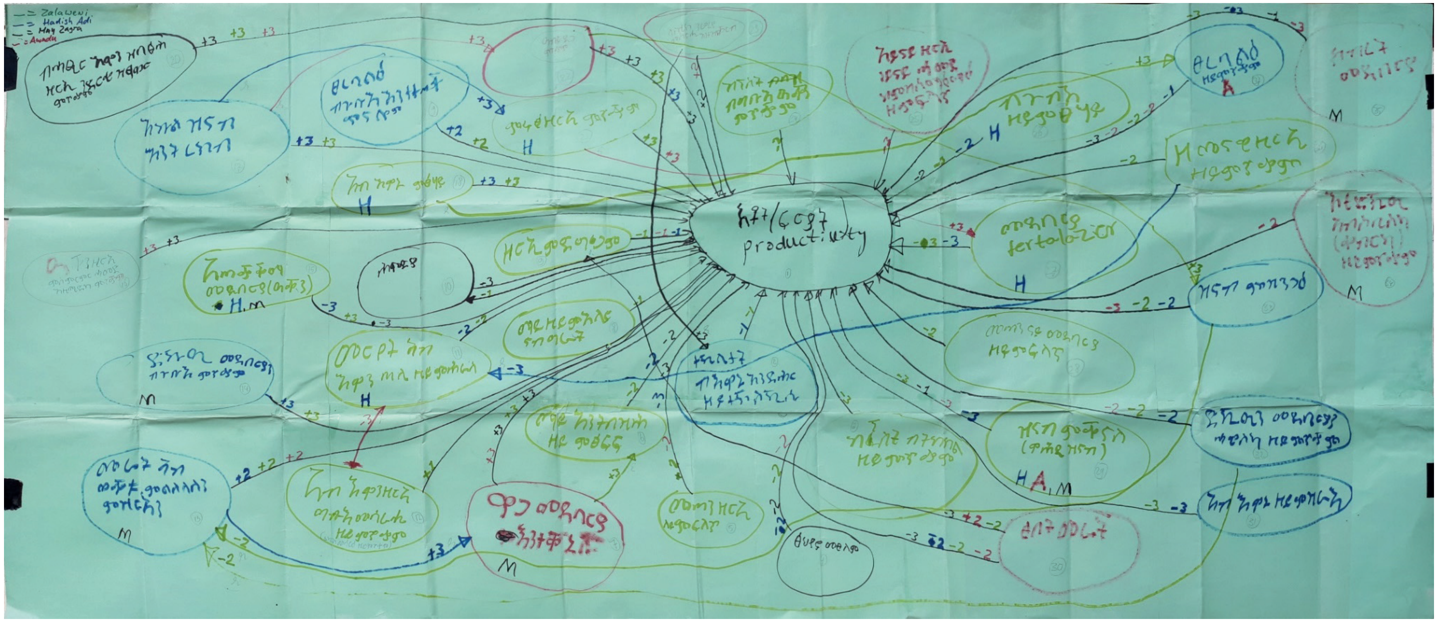


Figure 3.3d: Mind maps prepared in the workshops in the four locations: Hagere Selam.

Table 3.4: Radial diagrams showing *relative perceived impact* of constraints and opportunities on crop productivity for four locations in Tigray. *Relative perceived impact* is expressed as a % of the maximum. (swc = soil and water conservation).

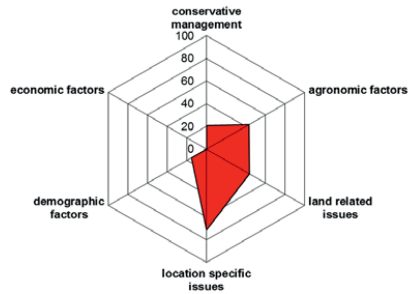
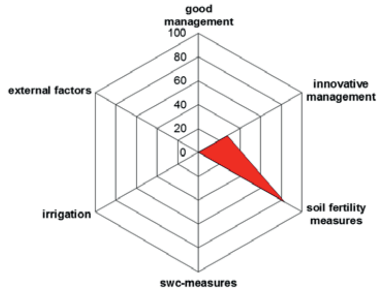
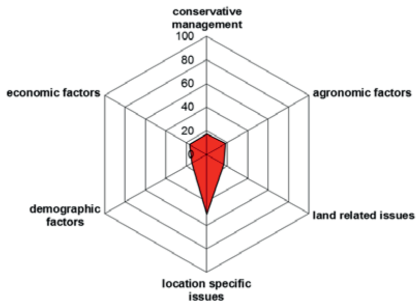
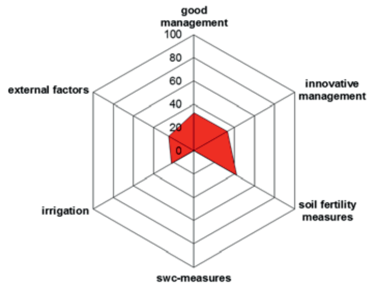
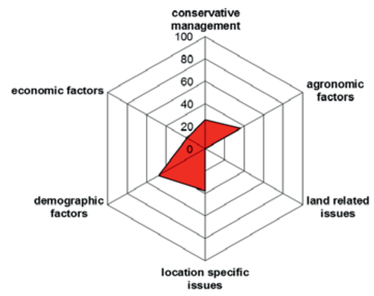
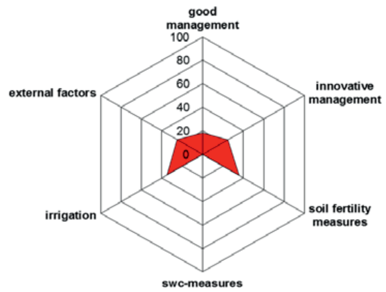
	constraints	opportunities
Edaga Arbi		
Hawzen		

Table 3.4 continued: Radial diagrams showing *relative perceived impact* of constraints and opportunities on crop productivity for four locations in Tigray. *Relative perceived impact* is expressed as a % of the maximum. (swc = soil and water conservation).

<table>
<tr><th></th><th>constraints</th><th>opportunities</th></tr>
<tr><td>Inticho</td><td>
</td><td>
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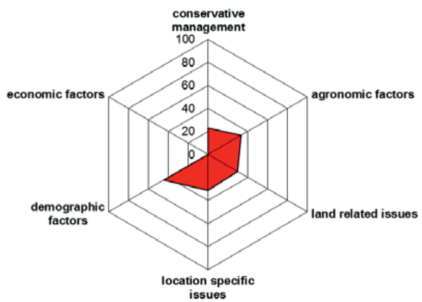
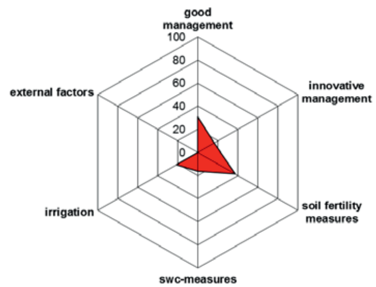
<tr><td>Hagere Selam</td><td>
</td><td>
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3.4. Discussion

3.4.1 Relating outcomes and context

Outcomes for the different locations varied with respect to the type of constraint or opportunity and the magnitude of relative perceived impact of these constraints and opportunities. Triangulating our findings with available descriptive data and observations (see Table 3.2), we found this variability in many cases in line with these. For example, outcomes for Inticho and Hagere Selam pointed to demographic issues as being most important. This aligned with the observation that these locations scored relatively low with respect to farm-size (Inticho and Hagere Selam), farm-family ratio (Inticho) and to some extent hiring index. The Edaga Arbi-groups, unlike all other groups, did not consider improved crop management an important factor in achieving higher crop yield. This matched with the higher availability of land in Edaga Arbi, as expressed in a relatively high farm-family ratio, which allows expansion of area under cultivation rather than leading to intensification.

The outcomes for three locations, Hagere Selam, Hawzen and especially Inticho, indicated a strong belief of farmers in irrigation as an opportunity. The active promotion of irrigation in these locations by BoARD and in the specific case of Inticho the presence of some rivers, the traditional links with markets and the past exposure to Eritrean irrigation systems supported this belief. In addition, the limited availability of land in Inticho also may explain the interest in intensification and the on-going development of small scale irrigation activities. Like many other farmers in Ethiopia (Hengsdijk et al., 2005), farmers from Edaga Arbi, Hawzen and Inticho appeared to consider soil erosion a long term risk as was reflected in the limited attention demonstrated for soil and water conservation. However, in Hagere Selam, soil and water conservation was considered relevant, which matched with the actual situation in Hagere Selam where its relatively intensive rainfall often leads to fatal short term flooding.

A common reservation with respect to FGD is that its outcomes might be influenced by coincidence. In our case, for example, the incidence of hail or severe drought at some moment preceding the workshop might have resulted in a shift of focus and, consequently, have influenced reproducibility. However, the fact that groups mentioned specific issues demonstrated that at that particular moment these where considered relevant. Conducting FGDs means including temporal dimensions of context and this by definition will affect reproducibility.

3.4.2 Reflection on process and procedure

The workshops generally went smoothly and without severe complications and participants were very committed. The fact that participants were mostly illiterate and came from underprivileged communities did not have much impact on the process. Former experience of farmers with workshop settings, like in the case of Hagere Selam, also supported the process.

Explanation of the questions was sought by the participants, demonstrating self-confidence. The knowledge generated in the process was meaningful and appeared to represent shared opinions from the groups.

Common forwarded sources of bias in FGD relate to power relations between participants, for example through domination of individuals or groups (Chioncel et al., 2003; Reed, 2008). As far as we observed, such dominancy, except for the central role of some spokesmen, was not taking place. In general, farmers expressed a good feeling about their participation in the workshops.

The selection of participants is often mentioned as a decisive factor in affecting outcomes of FGDs (Chioncel et al., 2003). In our case taking a simple random sample was not appropriate since participating farmers were expected to form groups with whom we intended to start a long-term process of experimentation and learning. Because of these preconditions we ended up with farmers that were all known to the FTC-staff and categorised by them as being potentially interested. Women were clearly under-represented, being only about 10 % of the participants. The actual number of female headed households was estimated around 30 %. Therefore, participants might not have been fully representative for the communities involved, in this way affecting generalizability. Another cause for biased outcomes often is an uneven distribution of wealth status, as pointed out by Byers and Wilcox (1991) and Hagmann (2000). However, in our case its distribution appeared acceptable.

Although procedure development was not the actual objective of our study, we mostly made pragmatic choices, using four groups in one workshop turned out to be very effective. Merging them during plenary sessions allowed groups and individuals to react on the findings of others. At the same time the use of connected questions on the same topic allowed participants to reconsider their previous viewpoints.

The workshops in fact were split into three parts in which a specific question was addressed. Each of these parts started with a discussion (a "true FGD") in small groups and was followed by a plenary discussion of all groups involved together resulting in the preparation of the final mind map. Designs using multiple focus groups are assumed to support verification of outcomes (Onwuegbuzie et al., 2009b). Communication and negotiation at different levels (in our case group and location) were used this way, in line with Chioncel et al. (2003), as a point of departure to describe reality.

Quantification of the FGD-outcomes was a main feature of our case study. Our main objectives for this quantification were: (1) to support a transparent analysis that was to be reported back to the farmers participating in our research project and (2) to allow comparison of the four locations. Essential in our quantification approach were categorization and the combination of frequency and attributed weight. The categorization was very time-consuming and resulted in just above 10 categories, which we considered as an acceptable trade-off between level of detail and allowing overview.

Although the use of frequencies in our quantification was very straightforward, the use of weights, on the contrary, implied that all groups involved used similar linear scales (De Groote et al., 2010). This was not the case and probably even impossible. However, the limited number of weights (three) and their later use relative to a location-specific maximum, might to some extent have compensated for these shortcomings.

In retrospect, the FGD-process and its quantification was divided into four main steps in which convergence or divergence of ideas and insights took place: (1) context and experience shaped ideas of individual farmers; (2) individual ideas merged into shared ideas of a group; (3) the opinion of the groups were represented by a mind map for their location; (4) issues presented on the map were categorized and based on this categorization translated into *relative perceived impact*. After these four steps these quantified findings were indeed confirmed by the groups involved (and by BoARD-staff) and then served as an input for the design of their experiments.

The experimental designs prepared by the groups were diverse and diverged; however, in all cases soil fertility measures had priority (Kraaijvanger and Veldkamp, 2017). The observation that all groups continued experimenting (Kraaijvanger et al., 2016b) on the topic initially identified for four years, suggested that the groups kept on considering it relevant. Convergence of ideas and insights took place in steps 1, 2 and 4; some divergence took place in step 3 as well as in the experimental phase following constraint identification (Fig. 3.4). However, convergence was the main process and consequently loss of "richness" most likely had occurred. In addition, since the experimentation method used was not fixed, farmer groups again were able to diverge (Kraaijvanger and Veldkamp, 2017).

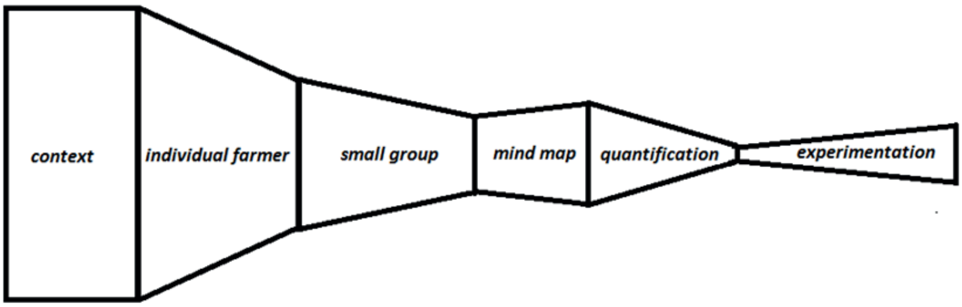

Fig. 3.4: Divergence and convergence taking place in different steps of our FGD-process (the vertical dimension reflects estimated richness of ideas and insights).

3.4.3 Relation with intervention work

Farmers experience a reality which is uniquely theirs and complex. The experiences and data we presented showed that farmer groups were well able to explore and identify local complexity. FGDs allowed the various contextual aspects, their interrelations and the way farmers perceived their reality to come out: the FGD-outcomes covered a wide range of constraints and opportunities and were indeed "rich and innovative" (Chioncel et al., 2003; Trenkner and Achterberg, 1991). Local specific outcomes generated through FGD-processes, therefore, might be very relevant in tailor-made intervention work. For example, addressing soil fertility issues was likely to gain resonance in Edaga Arbi, but in contrast to Hawzen, Inticho and Hagere Selam and Inticho a focus on irrigation might be less justified.

The step-by-step transformation of the mind maps into radial diagrams was able to maintain local diversity. This demonstrated that the qualitative nature of FGDs did not necessarily obstruct a wider application among diverse stakeholders in intervention work. A thoughtful quantification of qualitative outcomes, as we and for example Asfaw et al. (2012), Bellon and Reeves (2002), De Groote et al. (2010), Morris and Bellon (2004), Onwuegbuzie et al. (2009a) and Van Vliet et al. (2012) presented, might support building interdisciplinary bridges between the different paradigms generally held by both social and natural scientists (Mayoux and Chambers, 2005; Morris and Bellon, 2004; Neef and Neubert, 2011), bridges we consider essential for effective intervention work.

3.5. Conclusion

Intervention work aiming at developing agricultural productivity in low-external input settings requires an understanding of farmers' preferences and motivations and the complex socio-cultural settings in which these farmers operate. Macro- and mesolevel constraint analysis generally cannot take local complexities and farmers' perspectives into account and instead identify broad general concerns like nutrient deficiency or drought as key entry points for interventions.

In our case study we identified, using quantified FGD-outcomes, different constraints and opportunities that demonstrated considerable local variation in type and magnitude. Apart from this unexpected diversity, outcomes from all locations referred to location specific and agronomic factors as major constraints. Economic factors, overall, received limited attention. With respect to opportunities, participants overall considered soil fertility measures important.

Macro- and mesolevel approaches generated similar outcomes in our context but logically cannot address small scale diversity.

The alignment of our quantified FGD-outcomes with the context observed and their confirmation by local stakeholders suggested that the procedure applied resulted in differentiated, relevant and valid outcomes. Therefore, FGD definitely has, given its ability to deal with complexity at small scale levels, an important potential to provide an useful foundation for intervention activities aiming at improvement of local farmers' livelihoods.

In addition, in our specific case FGD not only generated useful information, but at the same time served as an adequate starting point for the participatory research envisaged: FGD allowed empowerment of the farmers involved by giving them a mandate and responsibilities at the initial stages of the experimentation process.

We concluded that FGD was able to identify local perceptions and preferences which were made more explicit by a purposive quantification of its outcomes. Such a quantification not only might be relevant in supporting a more pronounced and meaningful use in context-specific intervention work but, in addition, also may serve as a bridge between paradigms held by both social and natural scientists.

Acknowledgements

We want to thank Hidat Mesfin for translating and assisting with interviews and focus group discussions.

4 The importance of local factors and management in determining wheat yield variability in on-farm experimentation in Tigray, northern Ethiopia

Based on: Kraaijvanger, R., Veldkamp, A., 2015a. The importance of local factors and management in determining wheat yield variability in on-farm experimentation in Tigray, northern Ethiopia. Agriculture, Ecosystems and Environment 214, 1-9.

Abstract

Low crop yield in Tigray is one of the causes of food insecurity. Intervention work to increase yields, however, had only limited success and farmers often hesitated to adopt recommended practices. Considering this, we used participatory on-farm experimentation to arrive at best practices matching local preferences, complexity and context. Outcomes were evaluated at meta-level and at site level, respectively to identify major sources of yield variability and direct relationships between yield and treatment, location and soil properties. About 56% of the total grain yield variability in our experiments was explained by a linear regression model with management, altitude and N-fertilizer input. When management was excluded, still 49% of the grain yield variability was explained by altitude, N-fertilizer input, N-total, organic-C, rainfall and K-exchangeable of the soil. This indicated that grain yield was very location specific and related, next to treatment effects, to local climate and soil conditions. Excluding management, straw yield variability was explained for approximately 38% by including N-fertilizer input, the soil stoniness, soil P-content and the slope of the field as predictors. This indicated strong location dependent variability. Again excluding management, fertilizer responses were mainly explained by soil characteristics, which together with the inputs explained almost half of the total response variability. Focusing specifically on the relation between soil properties (N-total, P-available and K-exchangeable) and response to recommended fertilizer application we found this relation indeterminate, except for N. Differences in yields between recommended application and farmer managed fields were limited and non-significant. We concluded that: (1) defining best practices is a location specific and tailor-made task which requires the involvement of farmers to deal with local preferences and context; (2) on-farm experimentation included such local environment and farmer-related variability. Our participatory approach using on-farm experimentation demonstrated why a one-size-fits-all strategy, i.e. blanket recommendations, will not work unconditionally in Tigray. Both grain and straw yield were determined by the complex local interplay of farmer management, soil properties, landscape and fertilizer input.

4.1 Introduction

4.1.1 Background

Traditionally, agronomists often use on-station experimentation to design and test novel technologies that aim at sustainable increase of crop yield. In order to achieve reliability, replications and controls are always included in the experimental design. Experimental lay-out in most cases follows complete randomized block designs. The location variability is kept to a minimum by selecting flat non-shaded locations with uniform and usually deep well-drained soils. Local management is usually high tech. As a consequence of these choices, outcomes of on-station trials in Africa tend to be quite different compared to the actual situation in most farmer fields. Mugwe et al. (2009), for example, reported for maize, in response to specific treatments, an up to 50% higher yield on-station as compared to on-farm experiments. Due to its standardized conditions and procedures on-station research is considered more scientific and able to identify causal relationships (Johnston et al., 2003).

On-farm experimentation is, more than on-station experimentation, seen as an appropriate way to inform farmers about novel technologies (Chambers and Jiggins, 1987a). Objectives of on-farm experimentation relate to demonstration, testing or fine-tuning of novel technologies such as new crop varieties, fertilizer application or pest management. In many cases in on-farm experimentation, pre-defined technologies are evaluated to determine their suitability in a specific local context. Consequently, the reverse question, i.e. what technology is required in a specific context, often is ignored.

In on-farm experiments conditions are typically less uniform than in the case of on-station field trials. Consequently, substantial observed variability is controlled by local diversity in environmental conditions and farmer practices (Raman et al., 2011). If local variability in conditions and management is known, its relevance can be quantified and studied, allowing, in this way, an evaluation of the proposed technology. An important disadvantage of on-farm experiments in relation to intervention work is that outcomes are locally specific and, therefore, non-transferable to other locations and conditions (Johnston et al., 2003).

4.1.2 Context

In our study area, Tigray in northern Ethiopia, crop yield in general is low (Habtegebrial et al., 2007b; Kraaijvanger and Veldkamp, 2015b; Tsegay, 2012; Vancampenhout et al., 2006) and is often not sufficient to sustain rural families. Since alternative livelihood options are scarce, this often leads to food insecurity. This lack of food security is counteracted by food aid in the form of Food-For-Work-programs (FFW) or direct aid. In 2011 about 40% of the rural households depended for one month or more on such external support. Given this dependency, increasing crop production is considered an important option to achieve sustainable development of these rural communities. In the densely populated Tigray increased crop production can only be achieved by attaining higher crop yields. One of the main identified yield constraints in Tigray is soil fertility, which resulted in an extensive promotion of fertilizer use (Kassie et al., 2009) by the regional and *woreda* level Bureaus of Agriculture and Rural Development (BoARD) and different NGOs.

Within the framework of our research on participatory farmer experimentation we focused on soil fertility because the farmers involved identified this as a major opportunity to improve crop yield (Kraaijvanger et al., 2016a). In a participatory process we facilitated, by using focus group discussion, farmer groups to design different experiments. This resulted in a series of experiments that were conducted on-farm in four different areas in Tigray. Consequently, farm management and environmental factors, like climate, soil type and topography, and related to that yield potential were different (for details, see Kraaijvanger and Veldkamp (2015b)).

Our involvement secured that control experiments and replications were included and that the experimentation followed standardized procedures. Fertilizer quality and size of the experimental plots were constant and all fields were relatively flat. All measurements were done by the scientific team. In total four years of on-farm experimentation resulted in an extensive data-set on achieved yield, responses to fertilizer treatments and local environmental and farm management characteristics. In this paper only experiments with documented inputs were included.

4.1.3 Research questions

Different treatments in our experimentation were expected to result in differences in yield. Besides that, the low level of control in on-farm experimentation likely contributed to outcome variability by allowing environmental factors to become explicit. Constraints, as identified by the farmers involved were found to be depending on location (Kraaijvanger et al., 2015). Previous research (Veldkamp et al., 2001a) indicated that a significant part of yield variability can be explained by local field (i.e. site) and farm (i.e. management) variability. In line with this we hypothesized that at meta-level, in addition to treatment effects, a substantial part of the yield variability in on-farm experimentation can be explained by local environmental and management factors.

Our research questions:

1. To what extent can, at meta-level, on-farm yield variability be explained by treatment effects, by environmental factors and by management factors.

2. How does, at site level, yield achieved in on-farm experimentation, relate to treatment, location and soil properties.

4.2 Materials and methods

4.2.1 Field experimentation

In total 16 farmer groups were involved, coming from four administrative units (*woredas*) in Tigray. These *woredas* were Weri Lekhe, Hawzen, Ahforom and Dogua Tembien. Our experimental sites were located nearby the administrative centres of these *woredas* (respectively Edaga Arbi, Hawzen, Intcho and Hagere Selam; see Fig. 1.2). In this paper we referred to these administrative centres.

Important environmental differences between our experimental sites in these *woredas* related to altitude (Hagere Selam above 2300 m, others around 2000 m), climate (annual precipitation Hagere Selam 850 mm, others around 600 mm; data BoARD), parent material (Hawzen sandstone and shale, others mainly basalt) and soil type (Hawzen mainly Cambisols, others Luvisols and Vertisols (FAO-IUSS, 2006)). The sites also varied in crops grown (in all sites wheat (*Triticum spp.*) and *teff* (*Eragrostis tef*) were important, in Inticho also sorghum (*Sorghum bicolor*)).

For additional details about the locations we refer to Kraaijvanger and Veldkamp (2015b).

In our joint experimentation programme farmer groups were challenged, for four years, to design experiments with the objective to achieve improved crop yield. In addition to these farmer experiments, science based experiments were included. In this experimentation three crops were involved: wheat, *teff* and *hanfets*. *Hanfets* is a traditional local mixture of wheat and barley (*Hordeum vulgare*). In this paper we focused on wheat, which was included in the experiments by about 60% of the farmer groups.

Farmer based experiments were extremely diverse and involved, for example, combinations of organic and mineral fertilizers. Science based experiments involved recommended application of urea and DAP, additional supply of potassium and sowing in rows (see table 4.1). In contrast to the farmer experiments, these science based experiments in most cases were replicated and included controls (see Table 4.2).

In this paper the analysis relates mainly to two science based treatments with wheat: (1) recommended application of urea and diammonium-phosphate (DAP, containing N and P) and (2) recommended application of urea and DAP plus additional potassium fertilizer (containing N, P and K). In addition, yields of controls, treatments with documented inputs (e.g. single application of urea) and hosting farmer fields (FF) were included. In our evaluation only the first year of experimentation in a specific site was considered to avoid residual effects of fertilizer and manure applications.

Table 4.1: Characterization different treatments.

Code	Description
C	Control, no application of fertilizer
FF	Farmer field hosting the experimental block
R	Recommended application of fertilizer (100 kg/ha urea + 100 kg/ha DAP for Edaga Arbi, Inticho and Hagere Selam, 50 kg/ha urea + 100 kg/ha DAP for Hawzen)
R+K	Recommended application + 94 kg/ha KCL

Table 4.2 : Overview of replications per involved site in on-farm experimentation for four years.

Period	controls	Recommended application of urea and DAP	Recommended application of urea and DAP and additional potassium
February 2010-November 2010	3	3	3
May 2011-November 2011	2	2	0-3
May 2012-November 2012	2	1-3	0-3
May 2013-November 2013	2	1-3	0-3

4.2.2 Experimental management

The experiments were conducted on-farm in fields selected by the farmer groups. All fields were terraced, which is a common practice in Tigray. Within these fields conventional experimental blocks containing the different treatments were positioned central (Fig. 4.1). In most cases experimental blocks were composed of 15 plots in three rows of five plots, with the long rows along the contour lines. The plot size was 9.0 m^2 (3.0 x 3.0 m).

In 2010 the farmer-based treatments were positioned in the centre row for demonstration purposes; scientist-based treatments were distributed random over the remaining rows. In 2011-2013 all treatments were distributed randomly over the three rows. In the case of replications we considered lower, middle and higher positions in order to deal with fertility gradients in terraced fields (Vancampenhout et al., 2006). Main treatments (control , recommended application of NP and application of NPK-fertilizer) were replicated to deal with variability within the experimental block (see Table 4.2). This variability was assumed to be high, even in small fields, and related to processes like terracing, water distribution, erosion and sedimentation (Vancampenhout et al., 2006).

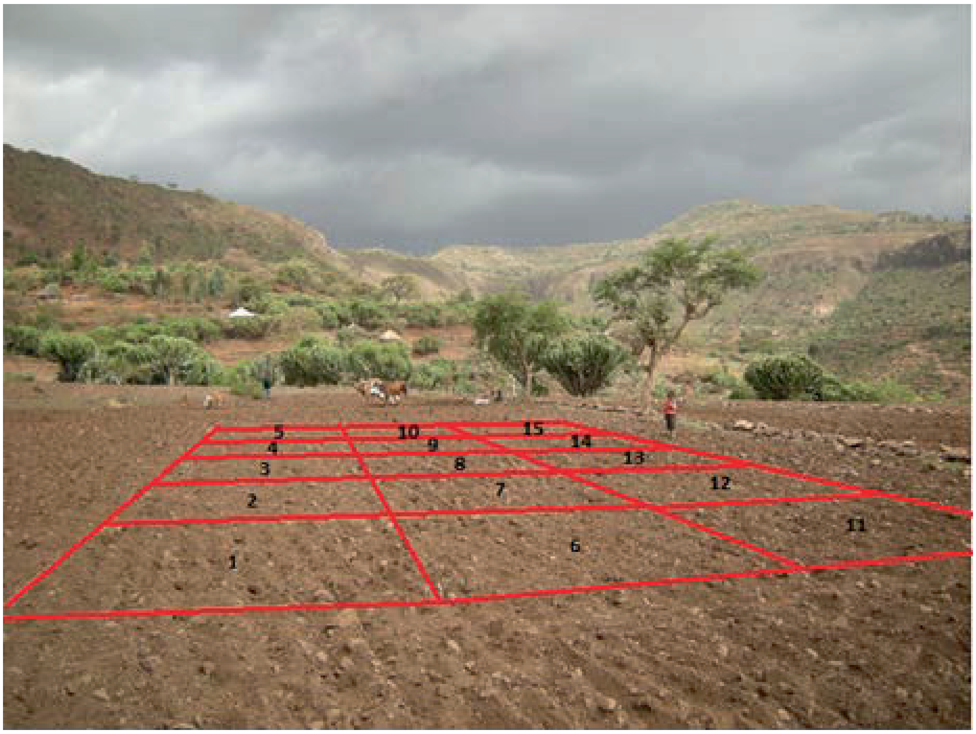

Figure 4.1: Experimental block within the (hosting) farmer field in Inticho.

A few weeks before sowing, composite samples of the topsoil (0-15 cm) within the experimental block were collected and analysed for total N (*N-total*, Kjeldahl method (van Reeuwijk, 2002)), available P (*P-av*, Olsen method (van Reeuwijk, 2002)), exchangeable K (*K-exch*, ammonium acetate extraction (Okalebo et al., 2002)), organic-C (based on loss on ignition (NEN, 2014)), clay content (estimated using reference samples) and stone content (2 mm sieve).

At the same time we delineated the extremities of the block and requested the responsible farmer not to apply fertilizers, manure or compost within this block. At sowing-time farmers broadcasted the seeds before final ploughing. Immediately after ploughing we applied, for each of the treatments, the required amounts of mineral fertilizers (with uniform composition) and incorporated them into the top soil. In most cases about one month after sowing, additional urea was applied, according to BoARD-recommendations, as a top dressing. All other management of the fields, like weeding and crop protection was done by the farmers, in most cases the owner of the field.

Harvesting was done by the research team, taking two random 1.0 m^2 samples within each plot. Representative samples (in duplo) from the hosting farmer field (FF) were taken adjacent to the experimental block. Harvesting was done manually. The crop was first cut and then weighed immediately to determine total biomass. After that the grains were separated by hand and also weighed. Chaff was removed in the traditional way by wind. Composite samples were taken to determine moisture content for grain and straw. Three experimental sites were excluded from the analysis due to (fatal) damage caused by hail and flooding.

4.2.3 Analysis of outcomes

4.2.3.1 Calculation of yield and responses

Yield (in kg/ha) was calculated using measured dry matter yield of grain and straw based on the individual plots.

Responses were calculated using the following ratio:

Response = 100 x (Y_T – Y_C) / Y_C

Y_T = yield treatment (kg dry matter/ha)

Y_C = yield control (kg dry matter/ha)

4.2.3.2 Overall variability assessment

Yield and response variability were statistically related to treatment-, site- and management factors. Treatments were different in N-, P- and K-inputs. Site characteristics were divided into three main groups: soil, climate and landscape (see Table 4.3). Soil properties we considered were soil organic carbon, stone content, clay content, nitrogen content, phosphorus content and potassium content (all of the top soil). Included climate factors were annual rainfall, mean maximum temperature (based on tabia, *woreda* and literature data) and length of growing period (based on experimental data). With respect to landscape we considered altitude (GPS measured) and field slope. To assess the potential impact of farmer management we classified the management-level, based on observations concerning weeding and soil protection (terracing), into three levels.

Table 4.3 : Variables used in the multiple linear regression models.

Variable	Unit	Range	Source
N-input	kg N/ha	0 - 75.5	experimental
P-input	kg P/ha	0 - 24	experimental
K-input	kg K/ha	0 - 49.1	experimental
N-total	mg/kg	360 - 2380	laboratory
P-available	mg/kg	3.67 - 83.3	laboratory
K-exchangeable	mg/kg	31 - 858.9	laboratory
Organic-C topsoil	%	0.5 - 4.7	laboratory
Clay topsoil	%	8 - 55	estimation
Stoniness topsoil	%	0.3 - 46.9	laboratory
Altitude	m asl*	1966 - 2639	GPS
Slope	%	1 - 12	clinometer, estimation
Temperature (mean annual maximum)	ºC	23 - 27	literature (Gebrehiwot and Van der Veen, 2013) for 2008.
Rainfall (annual)	mm	535 - 850	*tabia*- and *woreda* data (averages for the years 2005 - 2008 or longer)
Length of growing period	days	94 - 128	field observations
Management- level		1 - 3	field observations

* asl = above sea level

Statistical analysis was done on a plot based data-set, containing 128 data-points for wheat grain yield, 119 data-points for wheat straw yield, 102 data points for grain response and 93 data points for straw response. Variables were tested for normal distribution by using Q-Q plots. Only the normally distributed variables were used in multiple linear regression analyses to estimate significant regression models.

Assuming linearity the following general relationship can be provided to predict yield:

$\mu_y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \ldots\ldots\ldots\ldots + \beta_n x_n$

μ_{y} = yield of plot y

β_0 = constant

$\beta_{1\text{-}n}$ = coefficient for variable x

$x_{1\text{-}n}$ = variables

In our case we considered produced grains and straw (expressed as dry matter) and response (grain and straw) as indicators for yield. For the regression model of wheat response we excluded control treatments from the data-set. Estimations for β_0 - β_n were obtained by calculating multiple linear regression models using SPSS. For our exploration we used stepwise and backward elimination techniques.

The model fit of the regression-equations obtained was expressed by the coefficient of determination (R^2). This R^2 was used to indicate the total variability as explained by the included variables (=predictors). Standardized Beta-values and semi-partial correlation coefficients were calculated to indicate the relative contribution of individual and clusters of predictors. Standardized Beta-values informed us about the relative importance of a specific variable in the regression-equation; semi-partial correlation coefficients informed us about the unique contribution of a specific variable to the explanation of variability.

4.2.3.3 Yield per treatment and location

To evaluate the impact of specific treatments on crop yield we used both treatment and location as a unit of analysis. Average grain and total biomass yield of wheat were calculated based on site averages for a specific year.

4.2.3.4 Responses and soil properties

The responses to recommended application of urea and DAP (100 kg DAP/100 kg urea/ha, except for Hawzen 100 kg DAP/ 50 kg urea/ha) were related to different soil properties (N-total, P-av, K-exch and organic-C) and analysed for direct correlation. Soil nutrient content (N-total, P-av and K-exch) was evaluated using the ratings as provided by Landon (1991) (Table 4.4). In addition, based on these ratings, we defined three soil quality groups (low, medium and high) that matched our data range. To analyse differences in responses between these soil quality groups we used ANOVA.

Table 4.4: Ratings and corresponding soil quality groups for soil nutrient content.

Rating*	**Very low**	**Low**	**Medium**	**High**
N-total (mg/kg)	<1000	1000-2000	2000-5000	>5000
P-available (mg/kg)	-	<10	10-20	>20
K-exchangeable (mg/kg)	-	<60	60-120	>120
Soil quality group	**Group I (low)**	**Group I (low)**	**Group II (medium)**	**Group III (high)**

* Ratings are based on Landon (1991).

4.3 Results and Discussion

4.3.1 Yield and response variability

4.3.1.1 Overall explanation of wheat yield variability

Including all variables in the regression allowed us to estimate the contribution of the five main group of variables (inputs, soil, landscape, climate and management level) in explaining grain yield (Table 4.5 and 4.6). For this purpose semi-partial correlation coefficients were used to estimate unique contributions of specific variables to the explanation of crop yield variability.

When comparing the contributions of the different clusters of variables we observed that wheat yield is mainly related to environmental factors (soil and landscape), management and input (treatment). The unique contribution of climate related variables is relatively limited. Overall, this means that farmer-impact (management) by about 45 % was most important in explaining yield variability, environmental factors came second by about 31 % and treatment factors third by about 24 %.

Table 4.5: Outcomes of linear regression using all variables (dm=dry matter).

Dependent	**Grain yield dm (R^2 = 0.616)**		
Predictors	**Beta**	**Standardized Beta**	**Semi-partial coefficient of correlation**
Constant	$-4.30*10^3$		
N-input*	11.8	0.347	0.238
P-input	0.705	0.010	0.007
K-input	0.650	0.015	0.014
N-total	0.220	0.131	0.080
P-av	-8.65	-0.168	-0.094
K-exch	0.687	0.175	0.101
Organic-C	51.5	0.057	0.036
Clay	-10.3	-0.189	-0.087
Stone %	3.67	0.062	0.042
Altitude*	1.80	0.447	0.148
Slope	-54.7	-0.208	-0.116
Rainfall	0.457	0.067	0.016
Temperature	-4.68	-0.009	-0.004
Growing period	6.18	0.064	0.025
Management level*	509	0.433	0.324

Table 4.6: Unique explanation of predictors (all being included).

	Included predictors	% of total unique variance *
Sum inputs	N-input, P-input, K-input	24.3
Sum soil	stone%, clay, organic-C, N-total, P-av, K-exch	15.4
Sum landscape	altitude, slope	15.1
Sum climate	rainfall, temperature, growing period	0.4
Management-level	management-level	44.8

* Unique variances were calculated as the sum of squares of the semi-partial correlation coefficients (SSSP) of the predictors involved. To determine % of total unique variance we calculated the ratio of the cluster-based unique variance and the total unique variance (based on all predictors included in the regression model).

4.3.1.1 Significant relationships

Five different significant multiple linear regression models were derived from our data-set (Table 4.7): (1) grain yield, (2) grain yield (including management-level), (3) straw yield, (4) response of grain to fertilizer inputs and (5) response of straw to fertilizer inputs.

The multiple linear regression techniques applied resulted in the following regression equations:

(1) Wheat yield (grain) = $-3.66 \times 10^3 + 2.99 \times \textit{altitude} + 12.7 \times \textit{N-input} + 3.60 \times 10^{-1} \times \textit{N-total} - 3.81 \times \textit{rainfall} + 210 \times \textit{organic-C} + 6.52 \times 10^{-1} \times \textit{K-exch}$ ($R^2 = 0.487$)

The regression model indicated that grain yield variability was explained for almost 50 % by six variables. Standardized β-coefficients and semi-partial correlation coefficients indicated that in the case of the regression model for grain yield, altitude was the most important explanatory factor, N-input came second, followed by three soil variables (N-total, organic-C and K-exch). Rainfall had a negative contribution on yield within the regression model. It appeared that of the treatment factors especially N-input was relevant in explaining yield variability, of the site-factors both landscape and soil factors were important. It was clear that N-input positively contributed to grain yield.

(2) Wheat yield (grain) including management = -3.49×10^3 + 1.74 x *altitude* +12.3 x *N-input* + 536 x *management-level* (R^2 = 0.560)

When the wheat grain yield model included the estimated management-level, a small increase in total explained variability was observed. In the model only three explanatory factors remained: altitude, management-level and N-input. The strong contribution of management-level in this regression was striking. This was supported by our field observation that the visually best managed fields (no weeds) usually were also the most productive ones. This might be either due to the effort of the farmer or due to the fact that farmers, being constrained in labour, invested less time in less productive fields.

(3) Wheat yield (straw) = 2.37×10^3 + 29.2 x *N-input* - 48.2 x *stone%* + 42.4 x *P-av* +159 x slope (R^2 = 0.383)

The regression model for straw yield performed less well than that for grain yield. However, still more than 38% of the total variability was explained by the model. N-input was the most important explanatory variable, followed by two soil variables (P-content and stoniness) and one site variable (slope). In contrast to grain yield, N-total did not influence straw yield.

(4) Wheat yield response (grain) = -112 + 7.04×10^{-1} x *N-input* - 5.50×10^{-2} x *N-total* + 13.3 x *organic-C* + 1.05 x *clay* (R^2 = 0.411)

The regression model for wheat grain response explained 41% of the total variability. In this regression model N-total content of the topsoil was an important (negative) predictor: this meant that responses to fertilizer application (in our case in the form of urea, DAP and KCl) on the more fertile soils were likely to be smaller than on the poorer soils. The yield response was almost proportional to N-input; other important positive predictors were the topsoil properties organic-C and clay content.

(5) Wheat yield response (straw) = 33.8 +1.09 x *N-input* – 8.55×10^{-1} x *stone%* + 1.34 x *clay* -5.00×10^{-2} x *N-total* + 5.50×10^{-2} x *K-exch* (R^2 = 0.552)

The model for wheat straw response explained more than 55 % of the total variability. This model demonstrated the importance of fertilizer input and soil factors. It seemed that using N-inputs on the "better soils" (high clay and high potassium content) resulted in higher straw responses. This finding contrasted with the model for grain responses. The contribution of N-input and clay content to grain response was less and N-total even a more negative factor. This outcome probably related to the use of high-straw yielding varieties. Such varieties respond to N-input primarily by producing straw rather than grains. Despite the availability of improved short-straw varieties the traditional long-straw varieties were often more appreciated by the farmers.

4.3.2 Soil properties

Based on the ratings defined (see Table 4.4), N-total content over the whole range of sites pointed to a limited availability (Table 4.8). Only in two sites in Hagere Selam and one in Edaga Arbi nitrogen was having a medium availability. P-available and K-exchangeable appeared adequate in most cases. Still, in all *woredas* soils were found that were low in P. A possible cause for this might be long-term depletion. Potassium availability was limited in three sites in Hawzen. The specific sandstone and shale parent materials found in Hawzen, are reported to be responsible for the low availability of potassium (Murphy, 1959).

Table 4.7: Results of the multiple linear regressions (dm=dry matter)

Dependent	Predictors	Beta	Standardized Beta	Semi-partial coefficient of correlation
Grain yield dm[a] (R^2 = 0.487)				
	constant	$-3.66x10^{3*}$		
	altitude	2.99^*	0.745	0.436
	N-input	12.7^*	0.374	0.358
	N-total	$3.60x10^{-1*}$	0.215	0.151
	rainfall	-3.81^*	-0.556	-0.272
	organic-C	210^*	0.234	0.184
	K-exch	$6.52x10^{-1*}$	0.166	0.134
Grain yield dm (incl. management)[a] (R^2 = 0.560)				
	constant	$3.49x10^{3*}$		
	altitude	1.74^*	0.434	0.430
	management-level	$5.36x10^{2*}$	0.456	0.456
	N-input	12.3^*	0.363	0.360
Straw yield dm[a] (R^2 = 0.383)				
	constant	$2.37x10^{3*}$		
	N-input	29.2^*	0.435	0.429
	stone%	-48.2^*	-0.403	-0.346
	P-av	42.4^*	0.406	0.378
	slope	159^*	0.298	0.262

*significant (p=0.05), [a] stepwise regression , [b] backward elimination

Table 4.7 continued: Results of the multiple linear regressions (dm=dry matter)

Dependent	Predictors	Beta	Standardized Beta	Semi-partial coefficient of correlation
Response grain dm[b] (R^2 = 0.411)				
	constant	$-1.12 \times 10^{2*}$		
	N-input	$7.04 \times 10^{-1*}$	0.268	0.242
	N-total	$-5.50 \times 10^{-2*}$	-0.495	-0.411
	organic-C	13.3*	0.226	0.166
	clay	1.05*	0.298	0.204
Response straw dm[a] (R^2 = 0.552)				
	constant	33.8*		
	N-input	1.09*	0.458	0.420
	stone%	$-8.55 \times 10^{-1*}$	-0.236	-0.217
	clay	1.34*	0.413	0.330
	N-total	$-5.00 \times 10^{-2*}$	-0.493	-0.352
	K-exch	$5.50 \times 10^{-2*}$	0.242	0.200

*significant (p=0.05), [a] stepwise regression , [b] backward elimination

Table 4.8: Overview of nutrient composition of the top soil (averages for all experimental sites within a location).

						Limitations				
Location	**Total sites**	**Org-C average (range) %**	**N-total average (range) mg/kg**	**P-available average (range) mg/kg**	**K-exch average (range) mg/kg**	**no**	**N**	**NP**	**NK**	**NPK**
Edaga Arbi	12	2.4 (1.3-3.5)	1114 (550-2380)	28 (8-83)	341 (66-859)	1	10	1	-	-
Hawzen	12	1.4 (0.5-2.2)	788 (400-1610)	18 (4-38)	170 (31-626)	-	8	1	1	2
Inticho	12	3.4 (2.1-4.7)	1075 (690-1460)	29 (6-48)	281 (73-597)	-	11	1	-	-
Hagere Selam	9	3 (2.2-4.4)	1623 (970-2040)	27 (6-40)	328 (113-587)	2	6	1	-	-

4.3.3 Impact of treatment on yield

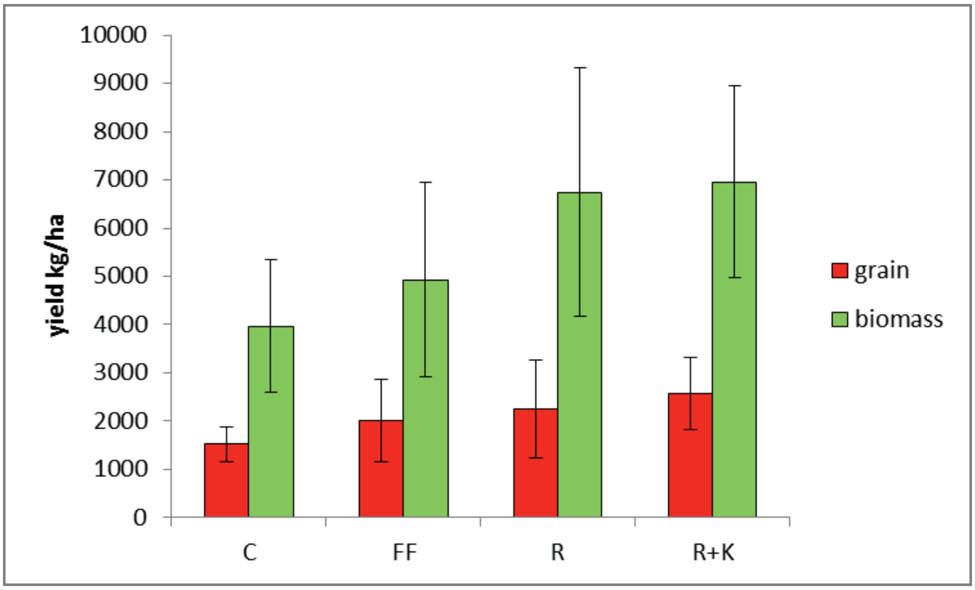

Figure 4.2: General overview of average yield for wheat for 4 years (on site basis). Standard deviation is indicated by error bars. (C=control, FF=farmer field, R=urea+DAP, R+K=urea+DAP+KCl).

Grain yield of wheat, compared to the controls, increased from about 1500 to about 2200 kg/ha in case of recommended application (R) of urea and DAP (see Fig. 4.2). In case additional KCl was applied (R+K) the increase of grain yield was even up to about 2500 kg/ha. However, differences between the grain yield of farmer fields (FF) and recommended application (R) and application of NPK (R+K) were not significant (p=0.05). In most cases farmers applied combinations of organic fertilizers and limited amounts of urea and DAP on their fields; these combinations appeared to be quite effective.

Recommended application (R) and application of NPK (R+K) had considerable effect on biomass yield, which almost doubled. Differences in biomass yield between farmer fields (FF) and recommended application (R) and farmer fields (FF) and application of NPK (R+K) were significant (p=0.05).

The application of NPK (R+K) provided results comparable to recommended application of urea and DAP (R), and consequently, did not result in significant differences in grain or biomass yield (p=0.05).

4.3.4 The impact of location on yield

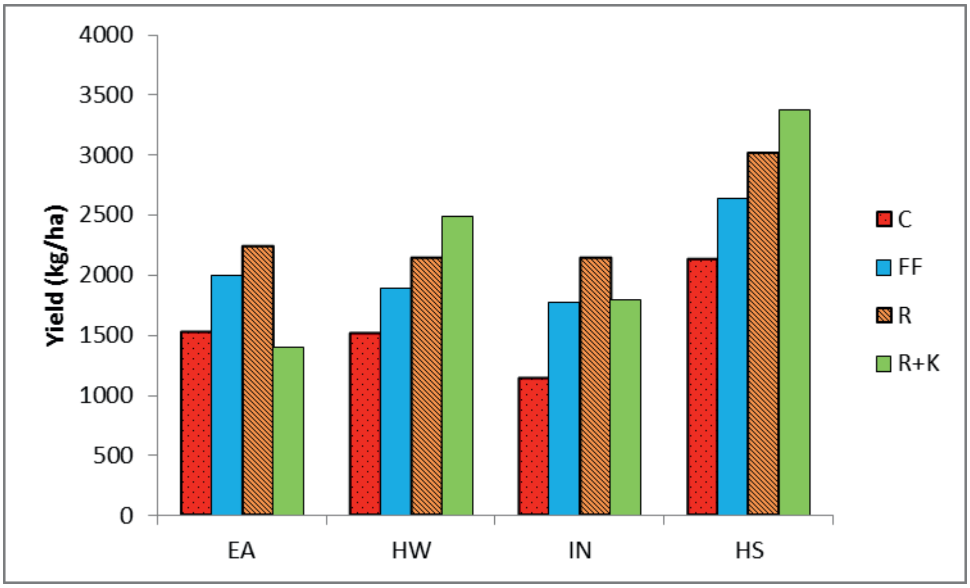

Figure 4.3: Overview of grain yield (dry matter) for 4 locations (on site basis) for wheat. (EA=Edaga Arbi, HW=Hawzen, IN=Inticho, HS=Hagere Selam, C=control, FF=farmer field, R=urea+DAP, R+K=urea+DAP+KCl).

Highest grain yield in the control plots was achieved in Hagere Selam, lowest in Inticho (Fig. 4.3). Hagere Selam is a highland area with an altitude of around 2300 m with lower average temperatures and a higher amount of rainfall. These conditions resulted over the years in soils with a higher organic matter content, which again results in higher natural soil fertility and a higher yield. In the case of both Inticho and Edaga Arbi altitude and soil type were similar. Still, soils in Inticho were less productive for all treatments. This might be a consequence of a more intensive land use and the frequent inclusion of sorghum in the rotation which might have resulted in nutrient mining (Kraaijvanger and Veldkamp, 2015b; personal observations first author). The low N-content of many of the Inticho soils also pointed to depletion (see Table 4.8).

Edaga Arbi and Hawzen achieved comparable yields for recommended application of DAP and urea. This was surprising since recommended application of urea in Hawzen was only half of that in Edaga Arbi. The location with a lower recommended fertilizer application (Hawzen) showed, as one would expect, a lower response to fertilizer application (non-significant; p=0.05).

The application of potassium, in combination with urea and DAP, led to a higher grain yield of wheat in the case of Hawzen and Hagere Selam. For Hawzen this matched with the soils that had a somewhat lower content of K-exchangeable. The good response to potassium in the case of Hagere Selam probably related to the incidence of higher achieved productivities, which required a more adequate supply of K. In addition, potassium often has a positive effect on the uptake of nitrogen (Mengel and Kirkby, 1987).

4.3.5 The impact of soil properties on response to fertilizer application

In this correlation only the sites that received a recommended application of 100 kg/ha urea and 100 kg/ha DAP were included. Both available P and exchangeable K did not show significant correlation with response to recommended application of urea and DAP. Only in the case of N-total (Fig. 4.4), correlation between response to recommended application of 100 kg/ha DAP and 100 kg/ha urea showed a significant quadratic trend (R^2 = 0.332, p=0.05). Low-N soils apparently benefited much more from the addition of N-fertilizer. High-N soils were productive in most cases and demonstrated limited response to application of urea and DAP.

Assuming that in Tigray total-N will be mostly based on organic-N, the availability of this organic-N will depend on mineralization in the rainy season (Bartholomew and Clark, 1965). However, this mineralization will take some time and will be proportional to the content of organic-N in the soil. Given the short growing period in Tigray (three months), mineral fertilizers therefore will be effective to supply nitrogen at the start of the growing period and prevent delay in crop development, especially in the case of low N-soils.

This correlation between total-N and crop response contrasted with the opinion that, in general, total-N is not considered a good indicator for availability of N (Landon, 1991). However, correlation between availability and total-N is assumed to improve when the soils considered fall within a relatively small range of soil fertility and overall local conditions are comparable (Bartholomew and Clark, 1965; Page and Dinauer, 1982), which did apply in our case.

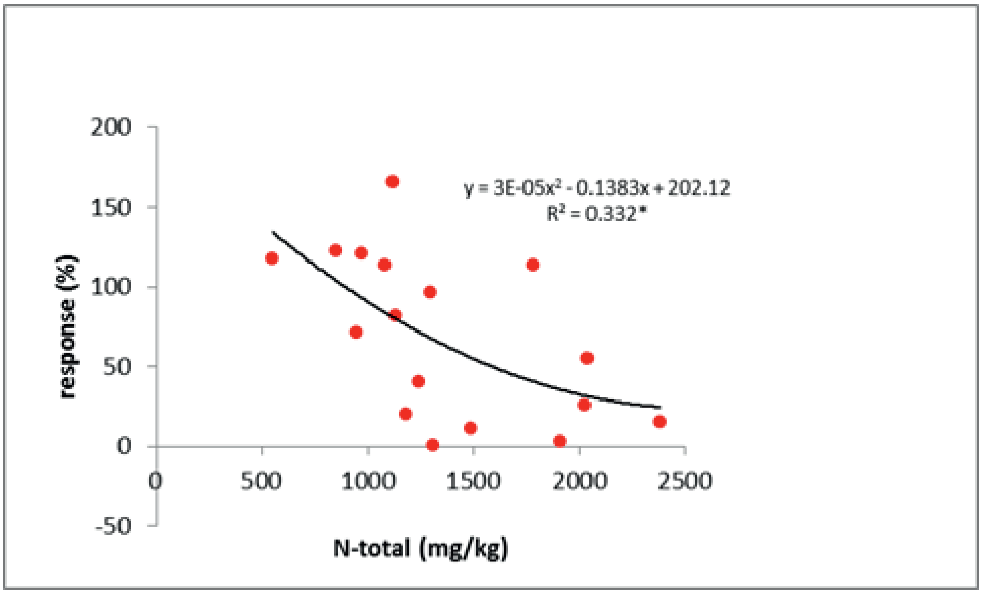

Figure 4.4: Grain responses of wheat to recommended application of fertilizer (100 kg urea/ha and 100 kg DAP/ha) versus soil N-total (* significant at *p*=0.05).

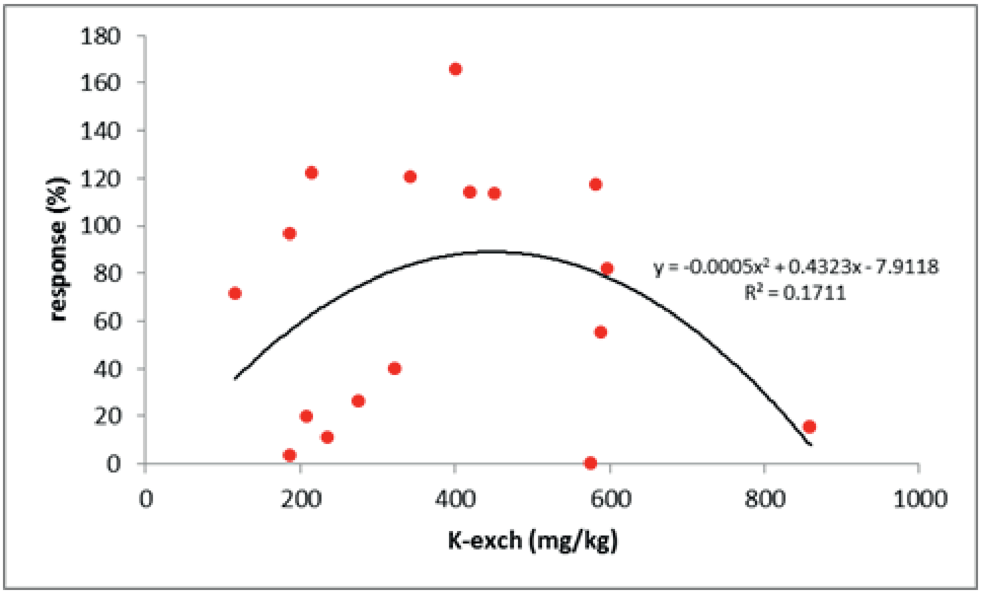

Figure 4.5: Grain responses of wheat to recommended application of fertilizer (100 kg urea/ha and 100 kg DAP/ha) versus K-exch (soil).

For K-exchangeable a weak quadratic trend (R^2 = 0.1711) was observed for the response to 100 kg/ha DAP and 100 kg/ha urea (Fig. 4.5). This appears to provide evidence for the concept of non-responsive poor soils and non-responsive fertile soils (Tittonell et al., 2008). In this case high potassium soils pointed to fertile soils, that were no longer responsive to the application of NP-fertilizers.

4.3.6 Evaluating overall impact of treatment and environmental factors on yield variability

The regression model for grain yield (without management) demonstrated that fertilizer input and local environmental factors (climate, landscape and soil) were both important in explaining 49 % of the total yield variability. N-input was the most important input factor, altitude the most important environmental factor. When management-level was also included in the grain yield model, the total explained variability increased to about 56 %.

Comparing unique contribution of the individual predictors confirmed the picture of different variables having impact on yield variability. Management-level (45 %) and environmental characteristics (31%) both accounted largely for the explanation of the grain yield variability. Variability explained by treatment factors appeared to have less explanatory weight (24 %). This indicated that a large proportion of wheat yield variability in the studied farms was determined by local factors that were location (landscape and soil) and farmer (management) related (together 76%). Compared to this the impact of fertilizer inputs on yield variability was relatively limited.

4.3.7 Arriving at recommendations

One of the objectives of our joint experimentation was to identify relevant best practices to improve crop yield in the context of the farmers involved. Interpreting outcomes of experimentation we observed that yield responses to recommended application of DAP and urea were highly variable and differences with farmer fields were limited. The same held for the application of potassium. The small difference in response between farmer fields and recommended application of urea and DAP is important in relation to (1) the trade-off between fertilizer cost and yield increase and (2) farmer fields and their (often more traditional) management being an important point of reference for farmers.

Most soils responded to NP-application, especially soils very low in N. However, responses were not convincing in all cases. This suggested that possibly other (micro) nutrients were a limiting factor. P and K are unlikely candidates because we observed in our experiments that available P and exchangeable K of the soil were medium or high in most cases. In such soils, high in P and K, one would expect an effective response to the application of limiting nitrogen. However, outcomes of our experiments did not confirm this. With respect to other (micro) nutrients, Habtegebrial et al. (2007a) previously suggested that, in the context of Tigray, application of S might improve performance of legumes. Next to nutrients also other effects appeared to be important, notably, management and crop factors. A simple straightforward measurement of only NPK-status of the soil, therefore, does not seem sufficient to support recommendations.

Consequently, clear recommendations on the basis of our findings, with respect to best practices cannot be provided so far. The complexity of the agricultural system demanded more detailed research on different interactions. Particularly the combination of organic and mineral fertilizers, that was often applied successfully by farmers in Tigray, deserves due attention. The NUANCES-project (Rufino et al., 2007) and Integrated Soil Fertility Management (ISFM) approaches (Vanlauwe et al., 2010), for example, illustrate the importance of these combinations.

The disappointing response of nutrient inputs, as compared to actual practice, indicated that at farm level probably other factors were more significant in increasing yield. Our analysis pointed to local management as a key factor. Total biomass yield responded better to recommended application of urea and DAP. Technically this offers the possibility to increase grain yield by using short-straw varieties. It is doubtful if farmers will follow such a recommendation because straw is considered important as a fodder for livestock in their mixed farming system (Kraaijvanger et al., 2015).

4.3.8 Yield variability in relation to on-farm experimentation

On-farm experimentation in our case resulted in highly variable outcomes. However, this variability was only to some extent caused by the low level of control in on-farm experimentation. Our findings demonstrated that treatment factors, environmental characteristics and management were able to explain over 60 % of the observed yield variability. Part of the on-farm experimentation variability in this way was attributed to local site and farmer characteristics. In this way the epistemological circle was closed since our on-farm experimentation was motivated by paying tribute to exactly these specific factors that represented the local context.

The apparent lack of control in on-farm experimentation in our case was counteracted by quantifying the control by the local environment and by farmer management. This allowed us to gain more insight into the farming system at hand than a normal on-station trial could provide. Environmental and farmer characteristics, therefore, need to have a more pronounced position in the evaluation of outcomes of on-farm experimentation. Different tools to support such analysis and even the identification of causal relationships are available. Examples of such tools are the use of aggregated indices like the Environmental Index in Modified Stability Analysis, multiple linear regression or advanced statistical models (Hildebrand et al., 1993; Raman et al., 2011; Riley and Alexander, 1997).

4.4 Conclusion

Linear regression of the outcomes of on-farm fertilizer experiments with wheat in Tigray indicated that 56% of the grain yield variability was explained by local management, local environmental characteristics and treatment effects. This implied that with on-farm experimentation also environment and farmer definitely mattered and needed to be accounted for.

Outcome variability in on-farm experiments in different locations was high and no simple clear and relevant relationships could be identified. Differences between the various introduced treatments and farmer fields were limited and non-significant. The main limiting nutrient was N. Responses to recommended (NP) fertilizer application demonstrated significant negative correlation with N-content of the soil. The correlation between P- and K-content of the soil and response to recommended fertilizer application proved to be negligible and not very helpful in arriving at general valid recommendations.

We concluded that defining best practices is a location specific and tailor-made task which required the involvement of farmers and their fields to deal with local preferences and context. Local management and local environmental characteristics mattered. On-farm experimentation involving farmers demonstrated why a one-size-fits-all strategy, i.e. blanket recommendations, will not work to solve all yield problems in Tigray. Yield was determined by the complex local interplay of farmer management, soil properties, landscape and fertilizer input. This complexity is not likely to be addressed in traditional on-station research and its outcomes.

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Supplementary data

Supplementary data associated relating to this chapter can be found, in the online version of the original article, at http://dx.doi.org/10.1016/j.agee.2015.08.003.


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5 Four years of farmer experimentation on soil fertility in Tigray, northern Ethiopia: Trends in research strategies

Based on: Kraaijvanger, R.G., Veldkamp, T., 2017. Four years of farmer experimentation on soil fertility in Tigray, northern Ethiopia: trends in research strategies. The Journal of Agricultural Education and Extension, 1-19.

Abstract

This paper analyses research strategies followed by farmer groups in Tigray that were involved in participatory experimentation. Understanding choices made by farmers in such experimentation processes is important to understand reasons why farmers in Tigray often hesitated to adopt recommended practices. A participatory experimentation approach was followed to arrive at recommendations matching with local preferences and context. In total, 16 groups of five farmers were monitored during four years. We monitored research strategy of the farmer groups by considering the following: (1) the type of treatments; (2) the inclusion of responsive treatments; (3) the actual responses achieved; (4) the treatments perceived optimal. We found that the farmer groups followed a very rational context-rooted strategy that, e.g., in its focus on straw production and the use of combinations of organic and mineral fertilizers, differed from that of the researchers involved and from standard scientific approaches in general. Consequently, in participatory experimentation, involvement of farmers in defining the actual experimental design is required to deal with local preferences and context. Outcomes of participatory experimentation are directly relevant for further outscaling of the technologies involved. In addition, insights and understanding obtained also might support upscaling in the form of designing rural development policies. Participatory experimentation processes are applied in development work for different reasons but often concentrate primarily on direct outputs. For development workers engaged in such processes, it is important to realize that actual involvement of participants in the whole process is equally important.

5.1 Introduction

5.1.1 Background

Crop productivity is low in many places ins sub-Saharan Africa and therefore affects rural livelihoods. Tigray, in northern Ethiopia, is not an exception and also here crop productivity is, in general, low and in many cases not sufficient to sustain rural families (Habtegebrial et al., 2007b; Kraaijvanger and Veldkamp, 2015a; Kraaijvanger and Veldkamp, 2015b; Tsegay, 2012; Vancampenhout et al., 2006). Development interventions in Tigray, therefore, aim at increasing crop productivity, for example, by improving management, by using external inputs and by irrigation. Within the context of Tigray, soil fertility is identified as an important constraint. As a consequence, the use of fertilizers is extensively promoted and extension-workers and NGOs recommend high application rates of DAP and urea (Kassie et al., 2009).

Despite these efforts, farmers generally hesitated to adopt recommended practices for various reasons. Alternative approaches aim at involving farmers more in development processes and in a less top-down and more participatory way (Biggs and Matsaert, 1999; Chambers and Jiggins, 1987b). Initiatives like Farmer Field Schools, Farmer Learning Centres, CIALs (Local Agricultural Research Committees), Communities of Practice and Action Research (Andersson and Gabrielsson, 2012; Braun et al., 2000; Duveskog et al., 2011; Mapfumo et al., 2013; Musvoto et al., 2015; Probst, 2002) aim at a collaboration of farmers and scientists to share and complement knowledge. Joint or participatory experimentation is assumed to result in sustainable and context-based change of rural farmer livelihoods (Ashby and Pretty, 2006; Sturdy et al., 2008; Van De Fliert, 2003).

5.1.2 Participatory experimentation

In participatory experimentation processes farmers and scientists provide different cognitive inputs and also use different sources of knowledge (Hoffmann et al., 2007). Differences in type and source of knowledge relate to differences in reference frameworks of involved scientists and farmers: academic vs. contextual and academic vs. pragmatic (Arévalo and Ljung, 2006; Leitgeb et al., 2011; Ramisch, 2014; Van Asten et al., 2009). In addition, also peers and social context in most cases are completely different (Chambers and Jiggins, 1987b). The combined result of these differences influences the process of participatory experimentation. Consequently, farmers and scientists involved in participatory experimentation will take different decisions, and both process and context will determine final constructs of scientists and farmers.

Farmers and scientists involved in participatory experimentation might work in a complementary way, for example, by providing different inputs or by covering different aspects of experimentation. A common model is that farmers take responsibility for contextual aspects, whereas scientists deal with introduction of novel technology (see, for example Arévalo and Ljung (2006) and Sumberg et al. (2003)). In such settings, farmers and scientists have complementary roles that even might lead to synergy (Vandeplas, 2010). In other cases, farmers and scientists co-operate on a basis of equality, and farmers have more responsibilities, for example, with respect to the design of experiments (Marquardt et al., 2009). Control over the research process by the farmers involved is important to address local complexity (Arévalo and Ljung, 2006; de Souza et al., 2012; Kraaijvanger et al., 2015). Still, in many examples of participatory experimentation, farmers merely provided information or tested pre-selected options and were not really involved in the process (Asfaw et al., 2012; Misiko et al., 2008; Ramisch, 2014; Staver et al., 2013; Waldman et al., 2014; Wani et al., 2014).

In participatory experimentation processes, by definition, many options will be left open: Will farmers follow the direction chosen by scientists or will farmers take the lead? Who decides on the included treatments, the number of replications and the selection of the experimental fields? Who is responsible for the final design and the analysis of outcomes? In addition, different scholars (for example, Marquardt et al. (2009) and Richards (1986)) remarked that farmers, by definition, experiment to create adaptive capacity and to make their livelihood systems resilient. Questions like these essentially can be summarized as to what extent farmers are able to follow their own research strategy.

5.1.3 Research strategy

Research strategies of stakeholders involved in participatory experimentation can be characterized by considering process inputs and outputs. Examples of inputs are traditional knowledge, experienced experimental outcomes, context and expert knowledge. Outputs might relate to the selection of treatments, responses achieved and treatments recommended. To some extent, inputs and outputs are a continuum in which responses (output) of one growing season serve as experimental experience (input) for the next round of experimentation (see, for example Baskerville and Wood-Harper (1996) and de Souza et al. (2012)).

Farmers, involved in participatory experimentation processes, will likely select responsive treatments that are within their reference framework, preferences and capacity. This means that besides maximizing response also context determines research strategy, which might become more holistic this way and less linear. For example, in Tigray, farmers use a mixed farming system, in which livestock is an important component (Abegaz, 2005). Therefore, farmers appreciate weeds (Kraaijvanger et al., 2015), trees like *Acacia albida* (in tigrinya called *Momona*) and the straw produced since these provide forage for their cattle. As a result of this context, farmers, for example, might prefer those treatments that produce much straw.

Scientists involved in participatory experimentation processes will likely select the most responsive and profitable treatments. In addition, scientists might follow a reductionist approach to identify crucial factors that have major impact on crop productivity. Following this research strategy, the most attractive opportunities will be selected, and understanding of the crop production system will be obtained. Whereas farmers' primary focus will be on context, scientists more often demonstrate a tendency towards generalization (Misiko, 2013; Ramisch, 2014; Van Asten et al., 2009).

Given these differences in views, knowledge on farmers' research strategies appears essential in participatory experimentation approaches, for example, to arrive at more relevant recommendations. At the same time, research strategies used by farmers reflect actual practice. Exploring these strategies might serve to optimize interaction and understanding between farmers and extension workers.

5.1.4 Research context

In our research project on the effectiveness of participatory approaches in development context, we involved farmers from Tigray, who typically use only limited external inputs, in a group-based participatory experimentation process for four years. We decided to give farmers the lead in this process and therefore deliberately did not interfere with their choices. Design of the experiments and interpretation of outcomes were, in line with Nederlof et al. (2004), part of their responsibility. In this way, i.e. independent of researcher inputs, we wanted to assess what choices the farmers in their experimentation would make and what progress they would achieve. Therefore, our inputs were restricted to facilitation of the experiments and introducing novel technology for the purpose of inspiration. In doing so, we wanted to know if and why farmers would adopt these technologies. Data collected during our involvement in this participatory experimentation were diverse and ranged from interview responses, monitoring participation and process, monitoring crop development, identifying various soil properties to measuring straw and grain yield.

5.1.5 Research processes

Phases in research processes are commonly depicted as a series of steps, starting with problem identification, followed by preparing the research design and the actual experimentation, and ending with the interpretation of outcomes and a conclusion. Such processes essentially have a linear character, but are often referred to as research cycles when two series of steps are connected. Examples are the experiential learning cycle with four steps (Kolb, 1984): experience-reflective observation-conceptualization-experimentation, the Action Research cycle with five steps (Almekinders et al., 2009): problem formulation-diagnosis-design-intervention-evaluation and the DEED (Describe-Explain-Explore-Design)-approach with four steps (Giller et al., 2011). In an agricultural context, Action Research and DEED are important concepts. In Action Research, technology development in combination with empowerment stands central; the DEED-approach focuses on identifying and adapting suitable technologies for specific contexts. In Action Research settings, researchers and farmers are more or less equally involved in participatory experimentation; in the DEED-approach researchers play a more dominant role.

5.1.6 Research objectives

Our primary aim was to analyse research strategies farmer groups followed in the course of their four-year involvement in participatory experimentation. Experimental outcomes were, in line with the concept of experiential learning and Action Research, expected to guide farmer groups in designing their research and in selecting treatments for the next experimentation year. Therefore, we hypothesized that groups based their strategy on previous experimentation and in this way achieved systematic progression.

5.2 Method

5.2.1 Description of experiments

Experiments were conducted in 16 sites, distributed over four *woredas* (medium scale administrative units) in central and eastern Tigray (for details see Kraaijvanger and Veldkamp (2015b) and Fig. 1.2). In each *woreda,* four farmer groups (with about five participants each) were active, each handling one experimental site. Four completed experimentation rounds took place in the period 2010-2014. The crops involved were wheat, *teff* and *hanfets* (a local mixture of wheat and barley).

Within the framework of our research on participatory experimentation, the topic of soil fertility was emphasized as a research topic as this was perceived by the farmers involved as a main opportunity to improve crop productivity in our study area (Kraaijvanger et al., 2016a).

In the participatory experimentation, farmers and researchers had different roles and responsibilities: farmers were responsible for the design and analysis of experimental outcomes and preparing a design for the next experimentation round, researchers facilitated the experiments, collected data and added some specific treatments to the experimental design. Both grain and straw yield were considered important variables and served as a main experimental reference for the farmers involved. Cost and labour inputs were also relevant but considered too complex to be provided as an direct input for the farmer groups. Soil data were provided to the groups upon request and when available.

The experiments were conducted on-farm, in a rather classical way with experimental blocks containing different treatments. The lay-out of these experimental blocks was in most cases 9 m x 15 m and contained 15 plots of 3 m x 3 m (Fig. 5.1). The block was situated central in the host field and its long side was parallel to the contour lines. Outside the experimental blocks, we monitored in the host field "*default*" farmer practice (here referred to as *"farmer field"*). In total, 928 plots were included in the experiments.

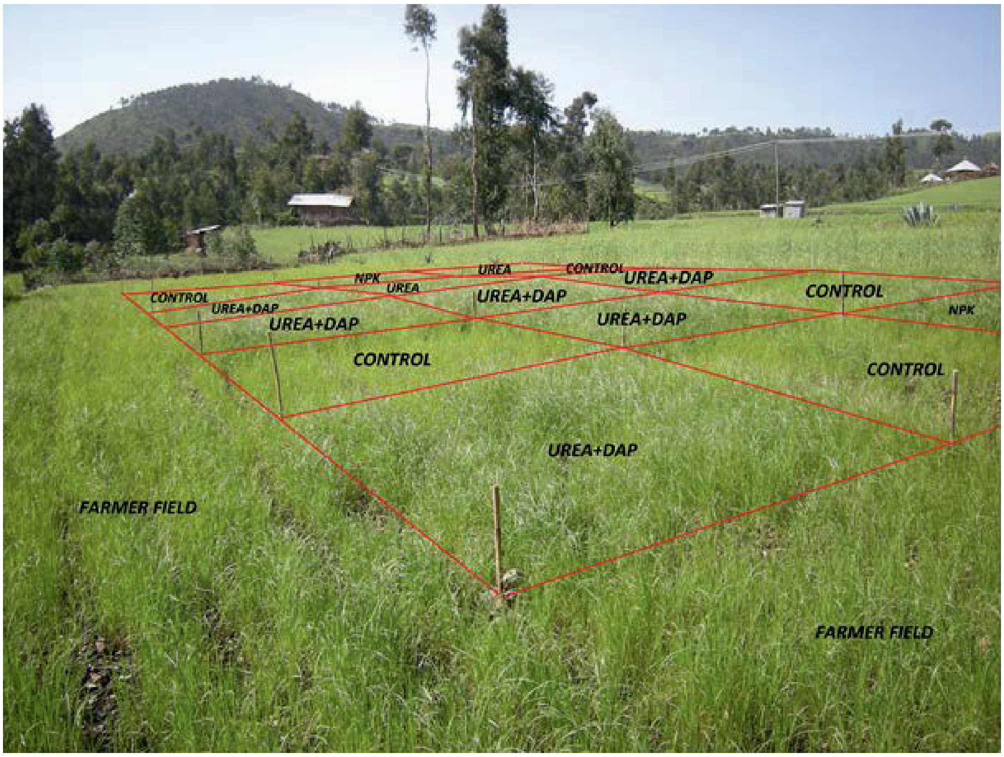

Figure 5.1: Lay-out of the second year (2011) experimental field in Dingelat.

Three types of experiments could be identified in our research:

1. Experiments designed by participating farmers, based on their views, ideas, experiences and analysis of experiments of previous years. Farmers prepared these designs through group discussions.

2. Experiments initiated by the scientists aiming at being an inspiration for the farmer groups to explore alternative ways to increase crop productivity. The experiments were mostly motivated by scientific presumptions. The status of these experiments, however, never went beyond being suggestive, farmers being free in selecting or rejecting them. Treatments in this category were selected based on outcomes of previous years, laboratory data, scientific curiosity and discussions with staff of the Bureau of Agriculture and Regional Development (BoARD) and Mekelle University (MU).

3. Experiments to secure the reliability, comparability and status of the research in the form of included replications and (zero-input) controls.

In this chapter, our focus is on the first group of experiments.

5.2.2 Management of the experiments

Harvesting was done by taking two random 1.0 m^2 samples within each plot. In addition, two representative samples from the *"farmer field"* were taken adjacent to the experimental block. Harvesting was done manually, first cutting and weighing the total crop, after that the grains were separated and again measured. Chaff was removed in the traditional way by wind. Composite samples to determine moisture content were taken for grain and straw in order to calculate yield on dry weight basis.

Experimental management, i.e., putting fertilizers and harvesting of the plots, was done by the researchers. All other management (like sowing, ploughing, terracing, weeding and fencing) was done by the host farmer in the same way as in the remaining part of the field. In a few cases, the group members assisted in managing the field, for example, by weeding it. The host farmer received a modest compensation to cover for yield losses caused by, for example, sampling and unproductive treatments.

5.2.3 Designing experiments

Farmers were in five workshops challenged to design experiments in the period from 2010 to 2014 (Table 5.1). These were scheduled about a month before the start of the growing season (July till October). The first workshop (2010) started without experimental inputs of previous years; in all successive workshops (2011-2014), data from previous experimentation served as an input. In the first workshop, we explained about the experimentation process and the design of experiments, using the same examples in all workshops. These examples referred to the use of different types and combinations of fertilizers (i.e., urea and diammonium-phosphate) and to different levels of fertilizer application.

In all workshops farmers in groups prepared a design, which together with our own inputs resulted in a lay-out for their experimentation. Groups were allowed to design freely, for example, by using the outcomes of previous experimentation in combination with their own preferences and views.

Table 5.1 : Overview of on farm experimentation with farmer groups and our inputs during four years.

Period	Inputs during workshop	Scientist inputs in experimentation
February 2010-November 2010	Use of controls, replications and comparing different treatments and levels	Recommended application of urea and DAP Application of 94 kg/ha KCl and recommended application of urea and DAP Controls (zero-input)
May 2011-November 2011	Outcomes 2010 experiments	Row sowing Recommended application of urea and DAP Controls (zero-input)
May 2012-November 2012	Outcomes 2011 experiments	Use of adapted levels of urea and DAP application Controls* (zero-input)
May 2013-November 2013	Outcomes 2012 experiments	Including digging and "optimal" treatment Controls* (zero-input)
April 2014	Outcomes 2013 experiments	

* in 2012 and 2013 some of the farmer groups also included controls

Field visits to an interesting experimental site were organized in each *woreda* a few weeks before harvesting. For this visit all four farmer groups from a *woreda* were invited to visit this site in order to observe and discuss the different plots. Attention was paid to overall performance but also to various aspects like, for example, crop height, size of ears and the number of grains.

During the second to fifth workshops, the groups were provided with charts showing the experimental layout, the outcomes achieved (yield for both grain and straw) and photographs visualizing achieved productivities of the previous year (Fig. 5.2). At the end of the workshop, groups indicated, in addition to the design prepared, also the actual fields for experimentation and the crops involved. For all successive workshops we followed the same procedure. In Table 5.1 an overview of the experimentation during these four years is provided.

From our side we included, in addition to the designs provided by the groups: controls (in all years, three replications in most cases), treatments following recommended fertilizer application (first year, in three replications), treatments testing response to potassium (first year, in three replications), row-sowing (second year, in two replications), modified application of urea and DAP (third year, in two or three replications) and opening the subsoil by using a pick (fourth year, two replications).

These deliberate inputs were motivated by, respectively, unknown responses of recommended fertilizer application, the possibility of nutrients other than N and P constraining productivity, the success of row sowing in other parts of Ethiopia, the observed problematic development of crops due to lodging (especially for *teff*, *hanfets* and traditional wheat varieties) and the presence of a dense subsoil (which might be a plough-layer or a B-horizon). However, these inputs were included merely to arouse discussion and were in no way imposed.

In the last experimentation year (2013), farmer groups were requested to indicate the treatment they perceived as best and served in a way as their recommended practice. These treatments were included (in mostly three replications) in the final experimental lay out of 2013.

Figure 5.2: Chart used by the farmer groups in the workshops.

5.2.4 Evaluating productivity and responses

Productivity (in kg/ha) was calculated using measured dry matter yield of grain and straw based on the individual harvested plots. To allow comparison between treatments for different sites and experimentation years, we focused on responses. Responses for treatments and *"farmer fields"* were calculated based on the (zero-input) controls:

Response treatment = $R_T = 100 \times (Y_T - Y_C) \; / \; Y_C$

Response *"farmer field"* = $R_{FF} = 100 \times (Y_{FF} - Y_C) \; / \; Y_C$

Y_T = yield treatment (kg dry matter/ha)

Y_C = yield control (kg dry matter/ha)

Y_{FF} = yield *"farmer field"* (kg dry matter/ha)

Change of response (Δ *response*) for each site was calculated as an average for the *"three best"* performing farmer-designed treatments after one, two and three years of involvement, using duration of involvement as a variable. In our final assessment we only included subsequent years in which crops were the same and fields (with respect to soil type) for a specific site were comparable:

Δ *response* = R_n - R_{n-1}

R_n = average response *"three best"* treatments year *n*

R_{n-1}= average response *"three best"* treatments previous year (*n*-1)

Change of response (*Δ response*) for all sites considered was averaged for, respectively, one, two and three years of involvement:

Average *Δ response* (over all sites) = Σ *Δ response* site / number of sites

5.2.5 Treatment selection

Our evaluation of treatment selection included four components: (1) the type of treatments that were selected; (2) the inclusion of responsive treatments of the previous year in the experimental design; (3) the actual responses the groups achieved in a specific year; (4) the treatments considered optimal by the groups at the end of their involvement.

Ad (1): Three types of treatments were indicated based on the composition of specific treatments with respect to the use of organic and mineral fertilizer (only mineral, only organic or a combination of both). In addition, three introduced treatments (the use of potassium, sowing in rows and the use of controls) were included in this evaluation. For each of the treatment types the percentage of groups that included this specific type was determined.

Ad (2): The extent to which the *"three best"* performing treatments (from the previous year) were included in the designs prepared by the farmer groups.

Ad (3): Grain productivity responses for the *"three best"* treatments were calculated for every group and for every year and compared with the responses achieved in the *"farmer fields"*. These calculated responses were averaged per group and overall. In addition, we visualized trends in achieved responses for specific farmer groups.

Ad (4): After three years of involvement in experimentation farmer groups indicated treatments they perceived optimal. To evaluate the performance of these specific treatments, separate responses were calculated for grain and straw.

5.3 Results

5.3.1 Types of treatments

The farmer groups included treatments that were extremely diverse and ranged from the application of different types of mineral and organic fertilizers (in all possible combinations), different dosages of mineral and organic fertilizers, the combination of row sowing with different methods of fertilizer application, to monitoring residual effects of fertilizer application in the previous year. During their involvement, farmer groups changed their strategy (Fig. 5.3). Especially their shift towards combinations of organic and mineral fertilizers was striking. This shift was at the cost of the application of solely organic fertilizers (manure and compost) and the use of recommended practices.

Another important change, more specifically related to their involvement in experimentation, was the inclusion of controls. The inclusion of two other types of treatments (sowing in rows and including potassium) was a reaction to our introduction of these treatments in the experiments. After an initially relatively high inclusion of these introduced treatments, farmer groups lost interest later on.

5.3.2 Selection strategy farmers

Analysis of the designs that were prepared by the farmer groups in the annual workshops informed us about the inclusion of good performing treatments from the previous year in these designs. Experimental outcomes in terms of productivity and response (compared to the control plots) indicated the progress that was achieved by the treatments selected by the groups.

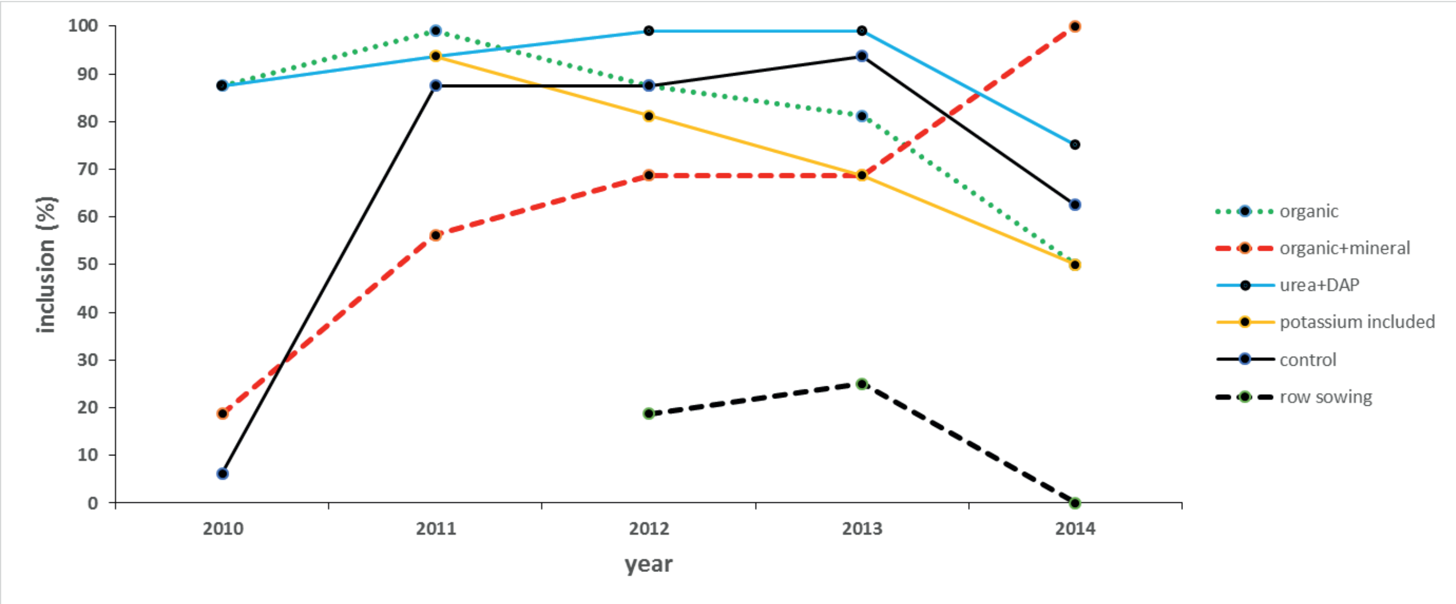

Figure 5.3: Inclusion of treatment types (as a %) by the participating farmer groups during the period of their involvement.

Groups predominantly included *"three best"*-treatments in their experimental designs (Table 5.2). However, in 2014, the percentage of included *"three best"*-treatments dropped. Average response of *"three best"*-treatments pointed overall to a maximum (84.1%) for the second year. After this peak, responses for many groups decreased and appeared to stabilize around 70%. Comparing achieved responses to *"farmer fields"*, the default option, indicated a convincing difference of about 40 %.

Table 5.2: Average proportion of included *"three best"* (performing) treatments (from the previous year) and average achieved response of the *"three best"* farmer designed experiments overall and compared with *"farmer fields"* for the experimentation years 2010-2013 for grains (standard deviation in brackets).

Year(s)	**Included *"three best"* treatments (%)**	**n**	**Average response of *"three best"* selected treatments (%)**	**Average response of *"three best"* selected treatments compared to farmer fields (%)**
2010		10	33.1 (25.6)	-5.1 (35.7)
2011	79.5	15	84.1 (44.2)	52.5 (56.7)
2012	70.8	13	65.4 (34.4)	32.3 (32.5)
2013	88.9	14	77.2 (50.8)	45.9 (43.7)
2014	55.6			
2011-2014	73.4			

The responses achieved by the individual groups were not in all cases progressive throughout (Figure 5.4). Change of crop and field had much impact and frequently resulted in much lower responses. For example, the Endamariam group grew *teff* in the second year; in the fourth year, the field was changed. In both cases, responses dropped considerably. The Awadu group grew *hanfets* (a local mixture of 70% wheat and 30% barley) and wheat on the same field during the first two years of experimentation with responses increasing above 100%. Responses, however, dropped when the field was changed in the third and fourth year. In Munguda, *teff* was grown for four years on comparable fields, allowing responses to increase progressively. These three groups achieved progress, but progress was not constant: comparable patterns were found for the other groups that participated.

By including only experimentation sequences for sites in which fields and crops were comparable, we found that average Δ *response*, in comparison to the previous year, was highest (61 %) after the first year of involvement (Table 5.3). After this initial change, average Δ *response* became limited. Still, variation between the groups was very high in the second and third year of involvement. Contrasting this in the same way with *"farmer fields"*, we observed on average a much smaller change in response; only after three years responses had increased.

Table 5.3: Average change in response compared to the previous year (Δ *response*) after 1 year, after 2 years or after 3 years of involvement in experimentation for *"three best"* treatments and *"farmer fields"* (considering similar crops and comparable fields; standard deviation in brackets).

	Treatments ("three best")		**Farmer fields**	
Duration involvement	**n**	**Δ *response* (%)**	**n**	**Δ response (%)**
1 year	11	61.2 (46.1)	9	-0.5 (79.8)
2 years	7	-2.1 (50.7)	6	-3.3 (80.0)
3 years	14	2.3 (61.7)	12	11.5 (70.6)

5.3.3 Optimal treatments

Farmer groups in their final experimentation year in most cases suggested effective treatments and achieved satisfactory responses (Table 5.4). The groups achieved overall significantly (p=0.05) higher responses for straw than for grains. More than half (10 out of 16) of the treatments considered optimal by the farmer groups were combinations of organic and mineral fertilizers. Contrasting these outcomes with those achieved on *"farmer fields",* we observed in most cases (eleven out of fourteen) higher (grain) responses for the suggested optimal treatments. Also on *"farmer fields",* responses achieved for straw were significantly (p=0.05) higher than for grains.

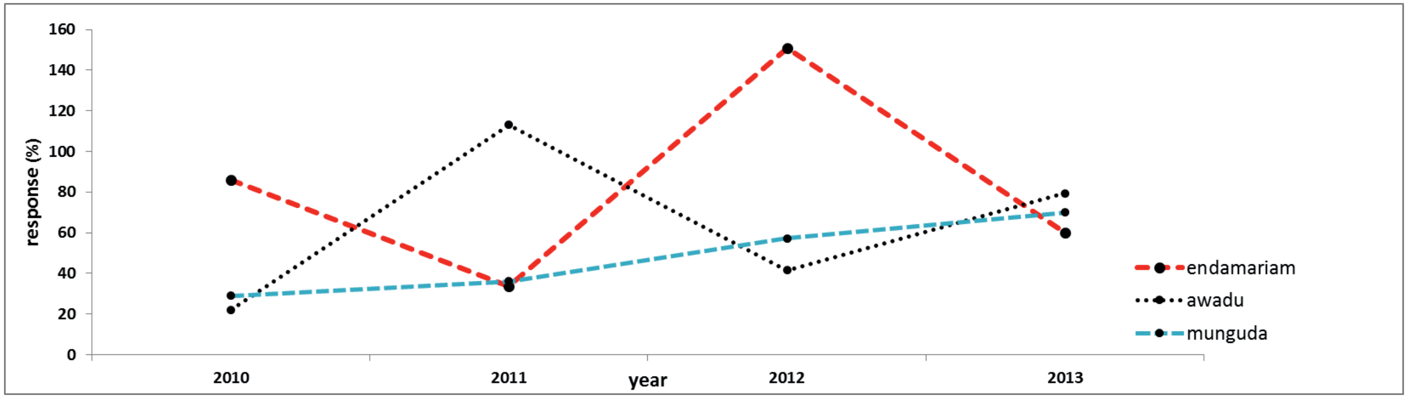

Figure 5.4: Examples of how average achieved responses of the *"three best"* selected treatments for specific groups changed during the years 2010-2013. The three groups included had different antecedents: Endamariam (wheat-*teff*-wheat-*hanfets*, in 2013 new field), Awadu *(hanfets*-wheat-wheat-wheat, new field in 2012 and 2013) and Munguda (every year *teff* on comparable fields). *Hanfets* is a local mixture of wheat and barley.

Table 5.4: Average productivity and response for grain and straw for treatments perceived as optimal by the farmer groups and response for grain and straw of reference *"farmer fields"* in the final experimentation year (dm=dry matter; standard deviation in brackets).

	Optimal treatments						Farmer fields		
Group	**Treatment**	**n**	**Grain average (kg dm/ha)**	**Straw average (kg dm/ha)**	**Response grain average* (%)**	**Response straw average* (%)**	**n**	**Response grain average* (%)**	**Response straw average* (%)**
Machalawi	Urea + DAP + manure	3	2086 (68)	2997 (281)	45.3 (4.7)	61.7 (15.1)	2	31.5 (16.8)	35.3 (15.2)
Awadu	Urea+ DAP + manure	3	2560 (420)	3612 (387)	49.6 (24.6)	51.3 (16.2)	2	31.3 (1.2)	35.2 (36.5)
Zalaweni	Urea + DAP + potassium + manure	3	1941 (552)	2465 (1052)	85.6 (52.7)	91.3 (81.6)	2	9,3 (7,3)	135.5 (79.8)
Siluh	Urea + DAP	3	1759 (65)	3155 (2909)	87.9 (6.9)	129.7 (21.1)	2	58.3 (27.4)	143.0 (75.6)
Mayzagra	Potassium	3	1223 (323)	2069 (732)	5.7 (27.9)	8.9 (38.6)	2	47.9 (5.9)	95.7 (69.0)
Tikuz	Urea + DAP + manure + ash	3	1714 (146)	5094 (439)	54.2 (13.1)	99.5 (17.2)	2	84.9 (18.5)	73.9 (35.5)

* Significant difference between grain and straw response (over all groups, $p < 0.05$)

Table 5.4 continued: Average productivity and response for grain and straw for treatments perceived as optimal by the farmer groups and response for grain and straw of reference *"farmer fields"* in the final experimentation year (dm=dry matter; standard deviation in brackets).

	Optimal treatments						Farmer fields		
Group	**Treatment**	**n**	**Grain average (kg dm/ha)**	**Straw average (kg dm/ha)**	**Response grain average* (%)**	**Response straw average* (%)**	**n**	**Response grain average* (%)**	**Response straw average* (%)**
Endamariam	Urea + DAP + manure + potassium	2	1065 (117)	4920 (547)	41.7 (15.6)	103.2 (22.6)	2	40,1 (32.7)	50,9 (25.4)
Biherawi	Urea + DAP + urea + manure	3	2514 (363)	3217 (284)	82.1 (26.3)	75.3 (20.9)	2	104.7 (30.5)	153.3 (119.2)
Adigudat	Urea + DAP + manure	3	1023 (432)	4243 (871)	-8.0 (38.9)	47.2 (30.2)	2	-19.6 (3.2)	13.8 (43.6)
Munguda	Urea + DAP + compost + potassium	3	831 (42)	4058 (670)	69.9 (8.5)	201.7 (49.8)	2	10.5 (70.1)	69.3 (57.9)
Mymisham	Urea + DAP + manure + compost	3	4214 (212)	5136 (253)	139.7 (12.1)	129.8 (11.3)	2	61.0 (9.3)	95.9 (79.7)

* Significant difference between grain and straw response (over all groups, $p < 0.05$)

Table 5.4 continued: Average productivity and response for grain and straw for treatments perceived as optimal by the farmer groups and response for grain and straw of reference *"farmer fields"* in the final experimentation year (dm =dry matter; standard deviation in brackets).

	Optimal treatments						Farmer fields		
Group	**Treatment**	**n**	**Grain average (kg dm/ha)**	**Straw average (kg dm/ha)**	**Response grain average* (%)**	**Response straw average* (%)**	**n**	**Response grain average* (%)**	**Response straw average* (%)**
Zonghi	Urea + DAP + potassium	3	1270 (190)	3763 (349)	-1.5 (14.8)	24.9 (11.6)	2	-2.0 (2.6)	46.6 (35.6)
Dingelat	Urea + DAP	4	2322 (422)	3893 (916)	120.6 (40)	140 (56.5)	2	39.5 (80.2)	93.4 (122.9)
Adowro	DAP + manure	2	3768 (274)	5946 (390)	9.6 (8.0)	31.1 (8.6)	2	-18.5 (16.3)	16.6 (33.7)
Gudowro	Urea + DAP	Not measured							
Adikolagol	Urea	Not measured							

* Significant difference between grain and straw response (over all groups, $p < 0.05$)

5.4 Discussion

5.4.1 Analysis of research strategies

Farmers basically used achieved productivity as a unit of analysis and consequently included outcomes of previous experimentation in their selections. Leitgeb et al. (2014) made similar observations in Cuba. In this way, farmer groups achieved positive responses, also when compared to the *"farmer field"* , their default practice. Data with respect to treatment selection demonstrated that, based on the information of preceding experiments, farmers selected treatments with an above average performance. Overall, a clear peak in achieved response was observed for the second year, after which responses remained more or less at the same level. Our initial hypothesis that response of selected treatments would be progressive due to preferential selection of good and exclusion of bad treatments proved incorrect. This appeared to be caused by changes in fields and crops (crop rotation) during the experimentation. Changing fields and crops in fact required a new " calibration" as alternative fields and crops likely had different properties and requirements.

In their final indication of optimal treatments, farmer groups came up with treatments that achieved responses for straw productivity that were significantly higher than those for grain productivity. This preferential selection of straw-rich treatments reflected the importance of straw in the farming system of the farmers involved, something which they also frequently mentioned in our discussions. In most cases, farmer groups considered combinations of organic and mineral fertilizers optimal, which matched with their actual practice. Combinations of organic and mineral fertilizers are often reported to give good results (see for example, Bedada et al. (2014)).

A standard agronomist strategy (in relation to soil fertility management), in general, aims at grain productivity. Given the somewhat disappointing responses (Kraaijvanger and Veldkamp, 2015b) to nutrient inputs (of N and P), a next focus would probably be on assessing if not, in line with the Law of the Minimum (Havlin et al., 2005), other factors were more important in constraining crop productivity. For example, crop management or specific nutrients other than N, P or K might be a limiting factor. In line with this, Habtegebrial et al. (2007a) reported, for instance, cases of S-deficiency in Tigray.

A general research strategy of the farmer groups can be deduced from their treatment preferences: (1) they selected the most productive treatments and (2) they used criteria relating to their farming system (importance of straw) and experience (combinations of organic and mineral fertilizers). Starting from a similar strategy (i.e. focusing on straw productivity), groups in this way arrived at different context-specific recommendations that matched with the complexity of their farming system. Also Misiko (2013), Ramisch (2014) and Van Asten et al. (2009) found that for farmers their own context is a main reference.

Random research strategies most likely had resulted in response levels close to, or even below, *"farmer field"* level, which was the case in the first experimentation year (2010). However, in our case, farmer experimentation resulted in treatments with relatively high response levels in later years (2011-2013) and, therefore, cannot be qualified as simply random. The fact that achieved experimental responses for their *"three best"* treatments were, in general, considerably higher than responses achieved on reference *"farmer fields"*, on the contrary, pointed to systematic experimentation. At the same time, the absence of change of response on the *"farmer field"* in the first two years of involvement also suggested that systematic experimentation took place: only after three years, a modest change of response on *"farmer fields"* was observed.

In their designs, farmers included suggestions that were provided by the scientists. However, they did this only when such treatments appeared relevant to them, using a *"contextual lens"*. For example, row sowing was initially included by some of the groups but left out later on. In contrast, digging the sub-soil, which was clearly a less successful treatment, was never included. This shows that *"goodwill"* was present but finally "*adoption"* depended on the results achieved in the experimentation. Therefore, farmers seemed to take rational decisions based on, for example, achieved productivity as compared to other treatments included. Similar observations were made by, for example, Hellin et al. (2008), Misiko (2009) and Totin et al. (2013). Farmers did not use scientific knowledge inputs *per se* and by default but more often combined scientific with their traditional and context-based knowledge.

Summarizing the different roles of inputs (experienced outcomes, tradition, context, scientist) and outputs (responses achieved, treatments selected, recommended practices) in relation to the research strategies observed, our findings indicated that responses achieved were a main (input) factor that determined research strategy and, more specifically, the selection of included treatments. In addition, also context and tradition guided the selection of treatments and the optimal practices indicated by the farmer groups. Consequently, the role of scientists in our participatory experimentation appeared rather limited in comparison to (experienced) responses, context and tradition.

In experiential learning and more specifically in Action Research experimental outcomes, in general, serve as an input to define research questions for the next research cycle (Almekinders et al., 2009; Kolb, 1984; Matsuo, 2015). In our case, experimental outcomes were definitely an input, but in a more indirect way since farmers used context as a main reference to analyse and design their experiments. Instead of pursuing a positivist approach in which new hypotheses and designs are based on previous research findings, farmers used research experiences and blended these with context and tradition to define new experiments. In comparison to standard Action Research settings, subsequent research cycles appeared less connected.

5.4.2 Relation with policy development

We often were surprised how farmers made choices so much different from those we would have made. Acknowledging such differences is important in achieving more effective experimentation. In addition, insight in choices farmers made and information farmers used is equally essential. Such insights not only serve in relation to the research itself, but also helps to identify choices made by farmers in their daily practice. Insights and understanding obtained through involvement in participatory experimentation, as a consequence, might inform policies in which introduction and development of suitable technologies to improve crop productivity stands central.

The identification of appropriate technologies through participatory experimentation, therefore, directly serves further outscaling, for example, through NGOs and extension work (Campbell et al., 2006). Authors like Vandeplas (2010) even consider farmer experimentation itself a form of outscaling. At the same time, insights and understanding derived from participatory experimentation also might support upscaling in the form of development of specific innovation policies and of policies aiming at rural development in general. This then adds to two other roles of participatory experimentation mentioned frequently: respecting farmers' objectives and context in order to arrive at meaningful recommendations (Chambers and Jiggins, 1987a; Defoer et al., 1998; Pretty, 1995) and empowerment (Mayoux and Chambers, 2005) of the farmers involved. Such policies might, for example, relate to food security, sustainable livelihoods, the introduction of novel technology or defining processes of out- and upscaling.

Instead of considering only externally planned interventions, local agency is also important since farmers' actions can be decisive in the success of interventions (Totin et al., 2015). At the same time, fully planned interventions, in general, are not desirable (Klerkx et al., 2010) and, on the contrary, space for change is required; not only in relation to the type of interventions (Sumberg et al., 2003) but also with respect to the actual processes involved (Leeuwis and Aarts, 2011). Rural development policies based on insights and understanding obtained through involvement in participatory experimentation not only respect farmers' preferences and views better, but also provide more space for change and, consequently, are likely to result in a more appropriate allocation of resources.

5.5 Conclusion

Evaluating farmers' experimentation strategy in a group-based participatory setting we found that:

(1) Farmers included the most responsive treatments of the previous year. This meant that the output of one year served as an (experienced) knowledge input for the next year.

(2) Farmers included treatments that were introduced by the scientists only to a limited extent in their experimental designs. It appeared that these were not in all cases considered relevant. Instead, they more frequently combined these introduced treatments with their own ideas.

(3) The type of treatments that were included by the farmers varied over the years. In the first year, they relied more on scientist and extension-based inputs, later on the treatments included much more bore their own contextual signature.

In the last experimentation year also controls were included which pointed to systematic experimentation.

(4) The yield responses achieved were relatively high, even when compared to actual farmer practice (on the same field). This indicated that farmers apparently did not follow random approaches but instead demonstrated a more or less systematic approach.

(5) The treatments that were recommended at the end of their four year involvement were diverse and appeared to focus more on straw than on grain yield. This again demonstrated that farmers indeed matched their design with the requirements of their livelihood system.

Farmer groups involved in our participatory experimentation based their experimental design on the outcomes of previous experimentation and achieved reasonable responses. Still, due to frequent changes in fields and crops, these responses were not progressive and stabilized around 70 %. Consequently, our hypothesis concerning progressive responses was falsified. In addition, farmer groups recommended treatments that were characterized by a focus on straw productivity and the use of combinations of organic and mineral fertilizers. The context of their farming system obviously served as a framework of reference for the farmers in relation to defining optimal treatments.

Scientists and farmers generally have separate backgrounds and operate in different contexts. Therefore, decisions made by scientists and by farmers in participatory experimentation processes will be different, leading finally to differences in experimental designs. In participatory experimentation and, more in general, in development work this understanding of different backgrounds and ways to arrive at learning and change is important. Since farmers' research strategy largely depends on context they should definitely have the lead to achieve meaningful collaboration. Insights and understanding obtained through analysis of outcomes and process of such participation modes are essential in supporting both outscaling of technology and upscaling through policy development.

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6 Grain productivity, fertilizer response and nutrient balance of farming systems in Tigray, Ethiopia: A multi-perspective view in relation to soil fertility degradation

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Abstract

Application of nutrients is an important way to increase crop productivity. In our study area, Tigray, development agents recommend fertilizer application to boost productivity and counteract nutrient depletion. We analyzed soil fertility from different perspectives, using responses and nutrient balances based on on-farm experimentation. Three perspectives, embedded in the People-Planet-Profit framework and different in temporal scale, spatial scale and ownership, were considered. Taking a farmer perspective we found no significant differences in response between recommended and current farmer practices. Taking an agronomist perspective available soil phosphorus seemed to limit the improvement of productivity by using fertilizers. It also became obvious that closing nutrient balances at field scale to achieve sustainability was difficult. Only by using considerable amounts of manure and at the cost of productivity this can be achieved. From a long-term environmentalist perspective the traditional agricultural system appeared sustainable in combining mixed farming and relatively low yields. Depending on the perspective taken, different pathways to transition will likely be forwarded. All three perspectives, however, indicated that gradually strengthening the existing mixed farming system by using fertilizers, organic manure and legume fallows will support crop productivity while maintaining other aspects of sustainability like food security and profitability. In line with this, our analysis of different perspectives suggested that in our study area farmers only will consider transitions with low risk and this should be addressed specifically in proposing pathways to transition. In processes where stakeholders with different perspectives co-operate it is important to be aware and make use of the possibilities of comparable multi-perspective analyses.

6.1 Introduction

In many rural livelihoods in sub-Saharan Africa, crop productivity plays an important role because it directly links with food insecurity, which is a major constraining factor in livelihood development.

Sustainability is a major concern in development issues and should ideally be viewed along People-Planet-Profit (PPP) dimensions (Elkington, 2002). Sustainable development requires transitions of current systems towards improved states in the future by means of innovations (Veldkamp et al., 2009), including in this way also a temporal dimension. Alternatively, the five capitals-model (Scoones and Wolmer, 2003), consisting of social, financial, human, physical and natural capital, is used to evaluate progress with respect to sustainable development. These five capitals match roughly with the People-Planet-Profit-model, 'people' including social and human capital, 'planet' including natural capital and 'profit' including financial and partly physical assets.

Sustainable development of livelihoods and land degradation are closely connected. Lacking a stable and robust sustainable system state often results in land degradation, whereas the incidence of land degradation frustrates sustainable development. Important forms of land degradation are soil erosion and nutrient depletion. Both are often attributed to exhaustive land use practices and both have a direct and major impact on crop productivity (Araya et al., 2011; Sanchez and Swaminathan, 2005). An important way to deal with nutrient depletion is the application of organic and mineral fertilizers. At present, several agricultural initiatives in sub Saharan Africa (SSA) relate to supply of nutrients. Examples are Integrated Soil Fertility Management (ISFM) (Vanlauwe et al., 2010), the Alliance for a Green Revolution in Africa (Jama and Pizarro, 2008) and Conservation Agriculture (Giller et al., 2009).

When considering fertilizer use, yield response in experimental trials and resulting overall nutrient balances are both important issues to consider. By including cost of fertilizers required, measured responses of applied fertilizers allow calculation of economic returns. Nutrient balances calculated at different spatial and temporal scales provide insight in the stability and sustainability challenges that the agricultural systems involved might face in the future (Lesschen et al., 2007; Smaling et al., 1996).

In Tigray, our study area, smallholder farmers using limited external inputs represent the majority of the agricultural population. For example, Haregeweyn et al. (2008) reported that only 10-20% of the farmers were using mineral fertilizers. In general, farm size does not exceed 0.75-1.0 ha, and many farmers experienced a scarcity of land to feed their family. In our study area, an estimated 40% of the rural population structurally depended on food aid (data provided by BoARD), despite attempts to improve productivity by introducing relatively novel technologies such as mineral fertilizers. This failure in being self-sufficient has put the traditional farming system under pressure, and given the limited environmental resilience, this may result in food insecurity, depleted fields and degraded land. Governmental development agents in Tigray therefore recommend the application of fertilizers at high rates (Kassie et al., 2009; Howard et al., 1999) in order to boost productivity and to deal with nutrient depletion. These recommendations are based on various trials starting from the 1970's (Gorfu et al., 1989).

With respect to nutrient depletion, various perspectives with different spatial and temporal scales and ownership can be taken. At a national scale for Ethiopia, Stoorvogel et al. (1993) calculated nutrient balances for NPK of -41, -6 and -26 kg ha^{-1} yr^{-1} respectively for Ethiopian farms. Haileslassie et al. (2005) found at a regional level annual NPK balances for Tigray of -9, 4 and -11 kg ha^{-1} yr^{-1}.

For some farms in Tigray, Abegaz et al. (2007) calculated slightly positive balances for NPK ranging from 3 to 6 kg ha^{-1} yr^{-1}. At field level, in the case of wheat grown by rich farmers, the calculated balance however was found to be about -40 kg ha^{-1} yr^{-1} for N and K and about -10 kg ha^{-1} yr^{-1} for P.

Farmers will not be so much aware of nutrient depletion as expressed in numbers, but will most likely compare yields on a temporal scale and relate this to perceived 'fertility' status. When taking a long-term perspective, one will observe that agriculture in Tigray already has existed for over 2500 years (Boardman, 1999) and that the apparent absence of major changes in farming systems might point to a certain degree of stability and sustainability. This suggests that in the long-term, net-depletion of nutrients was limited or in balance with basic input sources like weathering, dust deposition and legume fallow or reduced outputs due to crop failure (or disaster fallow), for example, because of hail or drought.

Different perspectives might lead to different interpretations and consequently to differences in suggested solutions and interventions. In discussing adequacy of stone bund construction to prevent land degradation in Tigray, Hengsdijk et al. (2005) indicated that such an intervention from a farmer perspective is not a preferable option in view of the loss of land. Nyssen et al. (2006), however, commented that from a long-term perspective benefits with respect to reducing soil loss, nutrient depletion and improving water availability are paying off.

In this paper, we will take three different perspectives, each with a different position in the People-Planet-Profit-framework, to discuss outcomes resulting from on-farm experimentation with the application of both organic and mineral fertilizers. In addition, on the basis of these outcomes, potential pathways to transition will be discussed and compared.

We hypothesized that perspectives, with different spatial and temporal scales and ownership, will lead to different interpretations of local productivity. As a consequence, the suggested pathways to transition towards improved system states were expected to be different too.

6.2 Materials and method

6.2.1 Study area

The experimental sites were located in four *woredas* (local administrative units) in Tigray: Werie-Leke, Hawzen, Ahforom and Dogua Tembien. To indicate these locations, we used the names and abbreviations of their respective administrative centers: Edaga Arbi (EA), Hawzen (HW), Inticho (IN) and Hagere Selam (HS) (see Fig. 1.2).

Altitude of the studied sites varied from around 2000 to 2300 m above sea level. Local rainfall depended on altitude and orography and was erratic and highly variable (Haileslassie et al., 2007; Nyssen et al., 2005). Annual precipitation ranged from 522 mm for Hawzen to 683 mm for Hagere Selam (Gebrehiwot and Van der Veen, 2013) and was distributed over two rainy periods, one from March till April and a long rainy period from May till August. Mean annual average temperature also depended on altitude and ranged between 15 ^{0}C and 21.5 ^{0}C (Araya et al., 2010).

The geology of the area was composed of different sedimentary rocks (sandstone, shale and limestone), covered and intruded by tertiary basalts. The combination of tectonic uplift and different lithologies resulted in a dynamic and very dissected landscape. On these different parent materials, Vertisols, Luvisols and Cambisols have developed. In general, these soils are naturally fertile as long as the parent material provides nutrients through weathering. Considering altitude and main lithology in the context of our study locations resulted in the following typology: (1) basalt highlands above 2300 m (Hagere Selam), (2) basalt highlands from 2000 to 2300 m (Edaga Arbi and Inticho) and (3) sandstone/shale highlands from 2000 to 2300 m (Hawzen).

6.2.3 Farming system

Most farmers in the study area practice mixed farming. Different cereals and pulses are grown to provide food for the household in a cropping system on the basis of frequent ploughing by oxen (Westphal, 1975). Cattle and small ruminants are grazing or browsing depending on the availability of grazing areas. Manure produced by livestock is collected and used as an organic fertilizer. At present, preparation of compost has become important, which also serves as a source of nutrients.

Wheat (*Triticum spp.*), barley (*Hordeum vulgare*), *teff* (*Eragrostis tef*) and faba beans (*Vicia faba*) are the main local crops, grown in the long rainy season. At lower elevations maize (*Zea mays*), sorghum (*Sorghum bicolor*) and finger millet (*Eleusine corocana*) may be planted in March but only become productive when both rainy seasons overlap. In traditional crop rotations, fallow periods with legumes are included to maintain productivity at a reasonable level. Crop failures were mostly related to shortage of rain and the incidence of hailstorms.

6.2.4 On-farm experimentation

On-farm experimentation was conducted for four consecutive years within the framework of assessing the effectiveness of participatory approaches to increase crop productivity. Because we were interested in the experimental choices that farmers made, we asked them to design experiments that were conducted within their fields.

Selected treatments ranged from single applications of DAP (diammonium-phosphate), urea, compost and manure to different combinations of these. The application rate for mineral fertilizers was in mostly 100 kg/ha but ranged from 50 to 150 kg/ha. For the organic fertilizer, application rate was mostly 4.4 tons/ha but ranged from 3 to 18 tons/ha.

In addition to the designs prepared by the farmers, we added treatments with recommended application of fertilizers (100 kg/ha DAP and 100 kg/ha urea, except for Hawzen 100 kg/ha DAP and 50 kg/ha urea), recommended application with additional potassium (94 kg/ha potassium chloride) and controls (without application of mineral or organic fertilizer). Potassium was included because pot experiments (unpublished data) indicated an improved response of nitrogen in combination with potassium application. The crops that were considered were wheat, *hanfets* (a combination of wheat and barley) and *teff*. Most of the sites were terraced and consequently nearly level.

Farmers were responsible for the practical management of their fields, i.e. ploughing, sowing and weeding. The experimental management, i.e. application of fertilizers and harvesting, was carried out by the scientific team. The size of the experimental plots was 9.0 m^2 (3 x 3 m); the size of most of the experimental blocks within the farmer fields was 9 by 15 m, allowing in total 15 treatments. The experimental blocks were situated within the farmer fields.

In most cases, recommended fertilizer applications, some specific treatments and controls were replicated three times within the experimental block. For harvesting, two random crop samples of 1.0 m^2 were taken from each plot. In addition two representative samples of 1.0 m^2 were taken adjacent to the experimental block, but still within the hosting farmer field. Harvesting and separation of seeds was done manually.

6.2.5 Laboratory analysis

Composite samples of the top soil (0-15 cm) of the experimental fields were analysed for total N, available P (as P-Olsen) and exchangeable K (see Chapter 4 for details).

6.2.6 Fertilizer response

Responses to fertilizer application relate achieved yield on the basis of dry matter to that of controls in the same field. Responses can be calculated as absolute or relative responses:

Response (absolute) = $Y_T - Y_C$

Response (relative) = $100\ (Y_T - Y_C)\ /\ Y_C$

Y_T = yield treatment (kg dry matter/ha)

Y_C = yield control (kg dry matter/ha)

In case applied fertilizer did not directly contribute to productivity, we assumed that it either became part of the soil nutrient stock or was lost from the system through leaching, volatilization or erosion. The agronomic use efficiency (AUE) of the applied fertilizer input (in our case nitrogen) was used to provide information about this (Vanlauwe et al., 2011):

$AUE = 100\ (Y_T - Y_C)\ /\ N_T$

Y_T = yield treatment (kg dry matter/ha)

Y_C = yield control (kg dry matter/ha)

N_T = applied nitrogen (kg/ha)

In many cases, responses are different for specific locations. It therefore makes sense to use a local reference to evaluate response and suitability of treatments. An example of such a local reference is the environmental index (EI), which is applied in modified stability analysis to evaluate the performance of specific treatments in relation to a local reference (Hildebrand et al., 1993). For this evaluation, different criteria can be used depending on objective and perspective; in our case the environmental index was defined as the average yield of different treatments (n) in a specific location:

$$EI = (Y_1 + Y_2 + \cdots + Y_n)/ n$$

$Y_{1, 2, \ldots n}$ = yield treatment (kg dry matter/ha)

Regression was used to evaluate correlation between response and soil characteristics; differences between different treatments were analyzed using analysis of variance. All statistics were conducted using MS-Excel.

6.2.7 Full and partial nutrient balances

Nutrient balances use, mostly on a yearly basis, gains (inputs) and losses (outputs) of the system with respect to nutrients. The nutrient monitoring (NUTMON) approach (Stoorvogel et al., 1993) initially used ten different inputs and outputs to prepare full nutrient balances. The inputs were defined as mineral fertilizers (IN 1), organic fertilizers (IN 2), deposition (IN 3), nitrogen fixation (IN 4) and sedimentation (IN 5). The outputs were defined as harvest (OUT 1), crop residues (OUT 2), leaching (OUT 3), gaseous losses (OUT 4) and erosion (OUT 5).

Because it was not in all cases possible to determine each input and output factor separately, we used partial nutrient balances to compare outcomes of the experimentation. These partial balances included IN 1, IN 2, OUT 1 and OUT 2. On a long-term scale the use of full nutrient balances is, however, essential. For this purpose, we used data derived from the nutrient balances prepared by Haileslassie et al. (2005).

6.2.8 Analytical perspectives

Experimental outcomes in the form of responses and nutrient balances were evaluated by taking three perspectives with different temporal and spatial scales and ownership. These perspectives were characterized by using a conceptual model that included the aspect of time scale and the three domains of the People-Planet-Profit framework (see Fig. 6.1). A set of keywords (e.g., nutrient stock, resilience) that related to the outcomes and context of the experiments was identified and included in the conceptual model. On the basis of this model three clusters, representing respectively the farmer, agronomist and environmentalist perspective, were identified:

1. Farmer perspective: focusing, in the context of Tigray, on risk minimization, economic returns and food security.
2. Agronomist perspective: focusing on economic returns, sustainability at field and farm level and understanding of soil-plant relationships.
3. Environmentalist perspective: focusing on long-term aspects of agricultural systems in Tigray.

The farmer perspective primarily focuses on short-term issues such as food security and economic returns and seeks to minimize risks in order to compensate for variability of, for example, weather, markets and policies. Food security links with farm size and family size, economic returns link with market, assets and responses.

Farmers do not consider response in relation to controls very important (Hoffmann et al., 2007) but are much more interested in the performance of novel technologies in relation to current practices on the basis of traditional knowledge and long-term experimentation. Under marginal conditions, farmers are interested to know if a specific application rate of fertilizer has reasonable returns at an acceptable financial risk. Value-cost ratios can provide such information (Donovan et al., 1999).

Within the People-Planet-Profit-framework, farmers focus on people (food security, traditional knowledge) and profit (economic returns). The planet aspect is covered mostly on a short-term scale, for example, by considering temporal productivity or the construction of terraces to prevent excessive degradation. Decreasing temporal productivity links with depletion of nutrient stocks.

Agronomists traditionally focus on economic returns and understanding soil-plant and input-output interactions. Recommendations are an important output for agronomists. Important issues are consequently productivity response, limiting nutrients, nutrient stocks and balances at field and, more recently, farm scale.

When taking the agronomist perspective, fertilizer responses and agronomic use efficiency will inform about profitability. On a short-term base, partial and full nutrient balances at farm and field level relate to changes in nutrient stocks. Understanding complexity at farm and field level aims at the development of balanced systems, of which ISFM is an important example. Within the People-Planet-Profit-framework, focus will converge to short-term aspects of profit (economic returns, responses), people (understanding) and planet (nutrient balances in relation to stocks).

Environmentalists will focus on aspects related to sustainability. Important issues are degradation, long-term nutrient balances, land use changes and landscape development. Environmentalists consequently will mainly focus on the aspect of planet and consider a long-term time scale. The environmentalist perspective will seek to relate findings of current experimentation to the past in order to discuss, in retrospect, the apparent sustainability of the agricultural system. To analyse and understand such historical agricultural systems requires the preparation of full nutrient balances and therefore the inclusion of reliable estimates for all input and output factors.

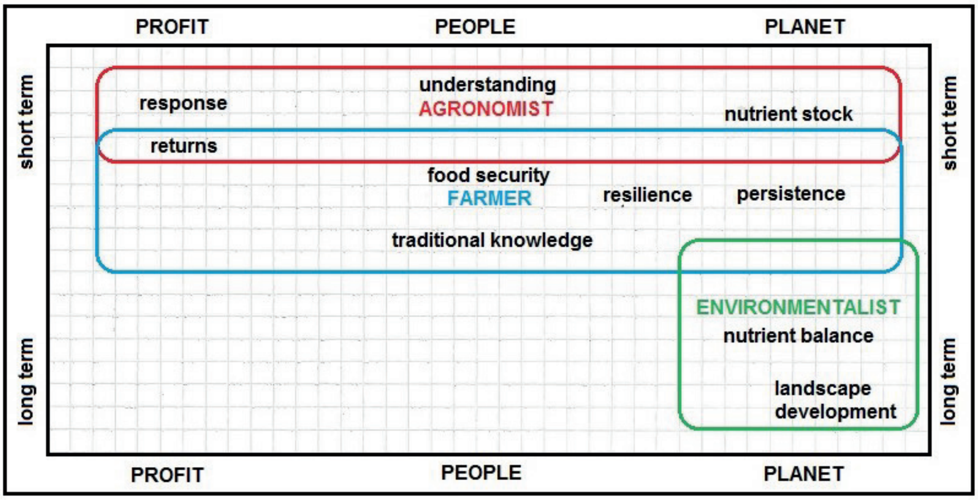

Figure 6.1: Different perspectives embedded in the People-Planet-Profit framework.

Table 6.1: Grain productivity (dry matter) and response of on-farm experiments (av res =average response; cv=coefficient of variation).

			Control			Recommended application*				Farmer field*			
site	year	crop	average (kg/ha)	n	cv %	average (kg/ha)	av res %	n	cv %	average (kg/ha)	av res %	n	cv %
Adigudat	2010	wheat	1234	6	19.7	1812	46.8	3	2.2	2256	82.8	2	17.3
Adowro	2010	hanfets	1316	7	23.6	2042	55.1	3	10.7				
Awadu	2010	hanfets	680	4	10.2	910	33.8	3	20.9	763	12.2	2	5.2
Biherawi	2010	hanfets	1215	4	17	1715	41.2	3	2.8	1930	17.7	2	42.3
Dingelat	2010	wheat	2077	6	41.6	2347	13	4	26.2	3404	63.9	2	6.4
Endamariam	2010	wheat	1105	4	35.3	2008	81.7	3	10.6				
Gudowro	2010	wheat	2399	3	10	3722	55.2	4	14.9	3011	25.5	2	7.3
Hadish Adi	2010	wheat	1676	5	9.4	2259	34.8	3	5.9	2731.5	63	2	0.5
Machalawi	2010	wheat	965	5	15.4	1237	28.1	3	19.6				
Munguda	2010	teff	776	4	14	1062	36.9	3	9.6	942	15.3	2	10.5
My Misham	2010	hanfets	1152	3	41.5	1786	55.1	3	20.8	1813	57.4	2	13.7
Zalaweni	2010	wheat	1596	3	33.5	1275	-20.1	3	2.4	1185	-25.8	2	5.7
Zonghi	2010	hanfets	1135	4	32.6	1330	17.2	3	13.2	1282	13	2	7.4

Table 6.1 continued: Grain productivity (dry matter) and response of on-farm experiments (av res =average response; cv=coefficient of variation).

			Control			**Recommended application***				**Farmer field***			
site	year	crop	average (kg/ha)	n	cv %	average (kg/ha)	av res %	n	cv %	average (kg/ha)	av res %	n	cv %
Adigudat	2011	wheat	1290	3	14.6	2757	113.7	4	13.5	763.5	-40.8	2	4.5
Adowro	2011	wheat	1516	3	18.9	3238	113.6	3	16.8				
Biherawi	2011	wheat	2137	2	7.6	2139	0.1	3	7.4	2054.5	-3.8	2	6.4
Mayzagra	2011	wheat	1956	2	2.2	3061	56.5	3	32.8	2750.5	40.6	2	9
Munguda	2011	teff	805	2	12.6	1079	34.1	4	7.8	837.5	4.1	2	14.4
Mymisham	2011	wheat	1351	3	35.4	2936	117.3	3	17.8	943.5	-29.8	2	13.4
Zonghi	2011	hanfets	670	2	36	1497	123.4	1	0	1374.5	105.2	2	16.6
Adigudat	2012	wheat	975	2	38.2	2588	165.4	1	0	2043	109.5	2	29.9
Awadu	2012	wheat	874	2	19.2	757	-13.4	1	0	1321	51.8	2	25.6
Biherawi	2012	teff	308	2	4.1	452	46.6	2	29.6	573.5	86.4	2	6.8
Gudowro	2012	wheat	2307	2	13.5	2906	26	4	20.6	2519	9.2	2	37.1
Machalawi	2012	wheat	1536	3	13.2	1708	15.3	2	16.1	1335.5	-9.8	2	29.4
Mayzagra	2012	wheat	2471	2	45.2	2905	17.6	2	12.9	2421	-2	2	10.1
Munguda	2012	teff	555	3	7.5	706	27.2	2	16.7	647.5	17.3	2	49

6.3 Results

6.3.1 Responses

Responses were very variable between different locations, years and crops (Table 6.1). Differences between responses for recommended application of fertilizer and current practice (farmer field) were limited and not significant (p = 0.42). The distribution over responses classes showed that most responses were in the 0 - 50 % class. Farmer fields scored higher than recommended application in the negative response class, whereas recommended application scored higher in the class above 100 % (Fig. 6.2).

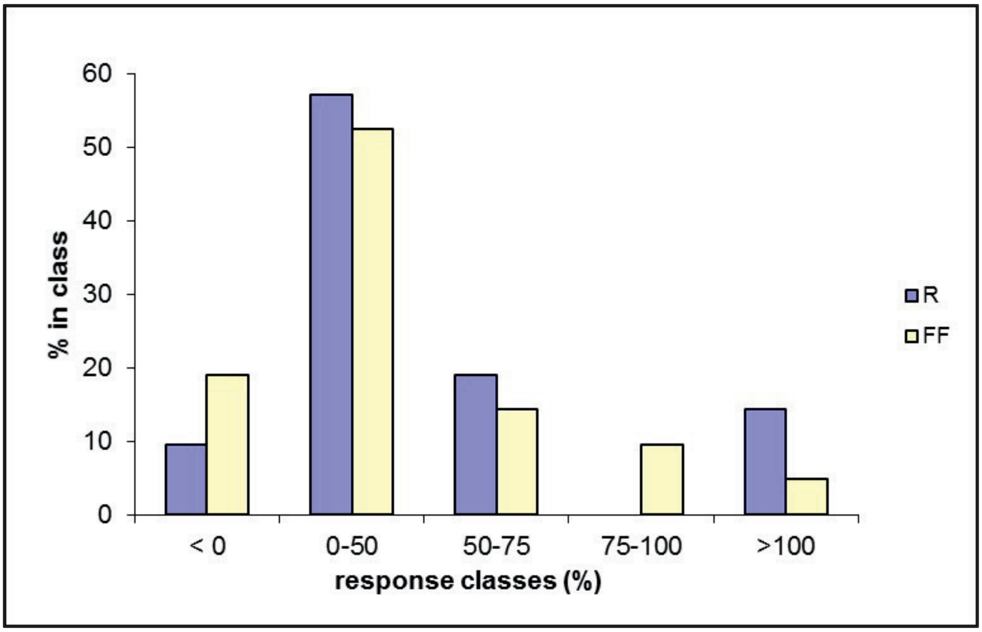

Figure 6.2: Distribution over response classes for recommended application (R) of fertilizers and as measured in adjacent farmer fields (FF) for wheat, hanfets and *teff* (n=22 for R, n=18 for FF).

Outcomes of the modified stability analysis resulted in regression lines for control and recommended application that were roughly parallel (Fig. 6.3). The distance between both lines (i.e. absolute response) corresponded with a difference of about 1000 kg in productivity. This meant that relative responses under better conditions, with most likely better soils, decreased. The regression for farmer fields resulted in a steeper line. Farmer practices consequently resulted in higher responses under better conditions and became then comparable with recommended application of fertilizer.

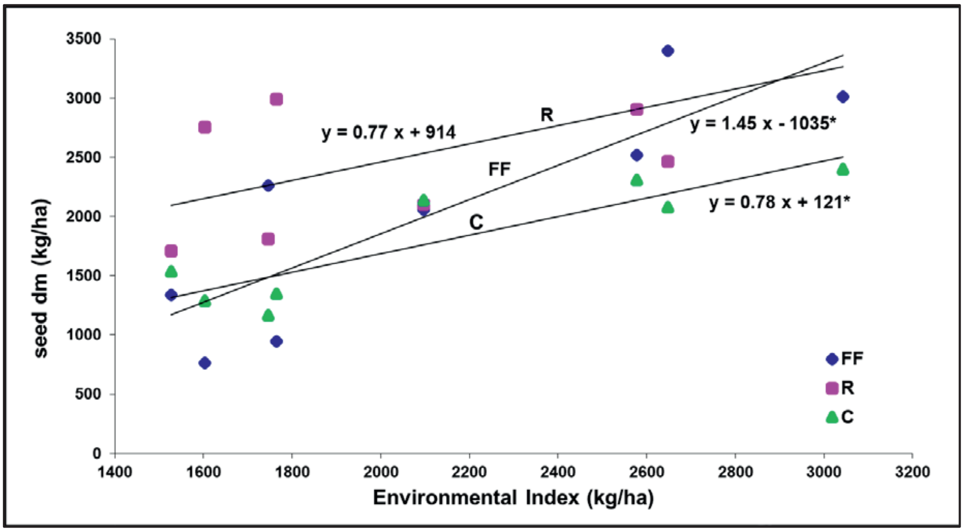

Figure 6.3: Grain productivity (dry matter) of wheat for control plots (C), recommended application (R; 100 kg DAP + 100 kg urea) and adjacent farmer fields (FF) vs. Environmental Index (*R-squares* for FF, R and C are respectively 0.73, 0.42 and 0.78; * = significant at p=0.05).

6.3.2 Site specific data

Rating the results (Table 6.2) of soil analysis (Landon, 1991), showed that in almost all sites N-total was low to very low (below 2000 mg/kg), P-available (measured as P-Olsen) was in most cases high (above 15 mg/kg) and K-exchangeable in most cases rated as adequate (above 120 mg/kg).

Table 6.2: Site characteristics and nutrient content of the involved study sites.

Site	Wo-reda	year	N-total mg/kg	P-av* mg/kg	K-exch mg/kg	Altitude (m)	Lithology	Soil group**	Landscape***
Adigudat	IN	2010	950	30.2	116.4	2165	basalt	Luvisol	gently sloping
Adowro	HS	2010	1270	12.9	113.1	2604	basalt	Luvisol	sloping
Awadu	HW	2010	560	27.8	201.3	2128	sandstone	Cambisol	very gently sloping
Biherawi	EA	2010	1040	11	211.2	2064	shale	Cambisol	gently sloping
Dingelat	HS	2010	1490	14.5	234.9	2543	basalt	Vertisol	very gently sloping
Endamariam	IN	2010	1130	48	597.4	2119	basalt	Luvisol	Very gently sloping
Gudowro	HS	2010	2040	26.4	588.6	2639	basalt	Luvisol	sloping
Siluh	HW	2010	520	25	194.2	2273	sandstone	Cambisol	gently sloping
Machalawi	EA	2010	1180	29.1	208.3	1966	basalt	Cambisol	gently sloping
Munguda	IN	2010	1120	18.7	332.5	2059	basalt	Luvisol	very gently sloping
Mymisham	EA	2010	1150	39.6	461.2	2321	basalt	Vertisol	very gently sloping
Zalaweni	HW	2010	530	14.7	155.2	2221	sandstone	Cambisol	gently sloping
Zonghi	EA	2010	890	22.7	66.1	1985	basalt	Luvisol	gently sloping

* Measured as P-Olsen

** Soil group according World Reference Base for Soil Resources 2006 ((FAO-IUSS, 2006)

*** Slope classes are defined as follows (Jahn et al., 2006): Very gently sloping (1-2%), gently sloping (2-5%), sloping(5-10%), strongly sloping (10-15%).

Table 6.2 continued: Site characteristics and nutrient content of the involved study sites.

Site	Wo-reda	year	N-total mg/kg	P-av* mg/kg	K-exch mg/kg	Altitude (m)	Lithology	Soil group**	Landscape***
Adigudat	IN	2011	1080	47.2	419.4	2133	basalt	Luvisol	very gently sloping
Adowro	HS	2011	1780	39.9	451	2504	basalt	Vertisol	gently sloping
Biherawi	EA	2011	1310	24.4	575.1	2064	shale	Luvisol	sloping
Mayzagra	HW	2011	920	20.8	60.4	2115	shale	Cambisol	very gently sloping
Munguda	IN	2011	1300	27.7	264.6	2049	basalt	Luvisol	very gently sloping
Mymisham	EA	2011	550	42.1	582.6	2313	basalt	Luvisol	gently sloping
Zonghi	EA	2011	860	15	69.3	1977	basalt	Luvisol	sloping
Biherawi	EA	2012	630	11.9	276.9	2033	alluvial	Cambisol	very gently sloping
Gudowro	HS	2012	2030	31.4	276	2665	basalt	Luvisol	strongly sloping
Machalawi	EA	2012	2380	83.3	858.9	1970	basalt	Luvisol	gently sloping
Mayzagra	HW	2012	1610	34.2	626.1	2129	shale	Cambisol	very gently sloping
Munguda	IN	2012	1460	26.6	329.8	2058	basalt	Luvisol	sloping

* Measured as P-Olsen

** Soil group according World Reference Base for Soil Resources 2006 ((FAO-IUSS, 2006)

*** Slope classes are defined as follows (Jahn et al., 2006): Very gently sloping (1-2%), gently sloping (2-5%), sloping(5-10%), strongly sloping (10-15%).

6.3.3 Nutrient balances

Table 6.3: Partial nutrient balances for different experimental treatments (for wheat and hanfets in kg ha^{-1} yr^{-1}).

Treatment	Average nutrient balance (partial*)		
	N	P	K
Control	-35.5	-9.5	-52.1
Compost	-22.3	-0.9	-18.8
Manure	-8.8	0.7	-14.9
Recommended	-6	6.4	-105
Recommended + potassium	-7.2	7.4	-44.8

* partial nutrient balances included only input of organic and mineral fertilizers and output of grains and crop residues.

Partial nutrient balances were negative for N and K. Applying recommended fertilizer or manure, however, resulted in a positive balance for P (Table 6.3). In case full nutrient balances were calculated, only manure resulted in a closed balance for N and a positive balance for P and K. The calculated balance for legume fallow had a positive balance for N, the balance for P and K was, however, still negative due to the effect of erosion (Table 6.4).

6.3.4 Response versus Soil Properties

Responses of recommended application of fertilizer in general did not show clear (linear) relationships with soil properties (see also Kraaijvanger and Veldkamp (2015a)). In this section therefore only outcomes for P-available in relation to recommended application of fertilizer, to performance of farmer fields, to absolute responses of recommended application and to responses in relation to landscape type were presented.

Table 6.4: Average full nutrient balances calculated for different experimental treatments (for wheat and hanfets in kg ha^{-1} yr^{-1}).

		IN 1 (fertilizer)			IN 2 (organic)			IN 3 (deposition)*			IN 4 (N-fix)*	IN 5 (sediment)*		
	n	N	P	K	N	P	K	N	P	K	N	N	P	K
Control	90	0	0	0	0	0	0	3.7	0.6	2.4	4	0.2	0.1	0.1
recommended	70	57.1	20		0	0	0	3.7	0.6	2.4	4	0.2	0.1	0.1
Recommended+ potassium	40	54.8	20	49.1	0	0	0	3.7	0.6	2.4	4	0.2	0.1	0.1
Crop failure (hail)	2	0	0	0	0	0	0	3.7	0.6	2.4	4	0.2	0.1	0.1
Fallow (legume)		0	0	0	0	0	0	3.7	0.6	2.4	18	0.2	0.1	0.1
Manure	21	0	0	0	33.7	12.1	47.5	3.7	0.6	2.4	4	0.2	0.1	0.1
		OUT 1 (harvest)			OUT 2 (residues)			OUT 3 (leaching)**			OUT 4 (gas)*	OUT 5 (erosion)*		
	n	N	P	K	N	P	K	N	P	K	N	N	P	K
Control	90	25.2	6.3	7.4	8	2.6	40.4	3	0	0	4.5	6	3	4
Recommended	70	44.5	9.6	11.9	16.6	5.1	85.7	3	0	0	4.5	6	3	4
Recommended + potassium	40	42.6	9.2	11.5	13.8	4.3	69.1	3	0	0	4.5	6	3	4
Crop failure (hail)	2	11.8	3	3.5	5.8	1.9	29.9	3	0	0	4.5	6	3	4
Fallow (legume)		0	0	0	0	0	0	3	0	0	4.5	6	3	4
Manure	21	23.1	5.2	6.4	7	2.2	35	3	0	0	4.5	6	3	4

		Balance (IN-OUT)		
	n	N	P	K
Control	90	-39	-11	-49
Recommended	70	-9.6	3	-99
Recommended + potassium	40	-7.2	4.2	-33
Crop failure (hail)	2	-23	-7.2	-35
Fallow (legume)* **		8.4	-2.3	-1.5
Manure	21	0	2.4	4.6

* data from Haileslassie et al. (2005)

** adapted from Haileslassie et al. (2005)

*** calculated based on Haileslassie et al. (2005)

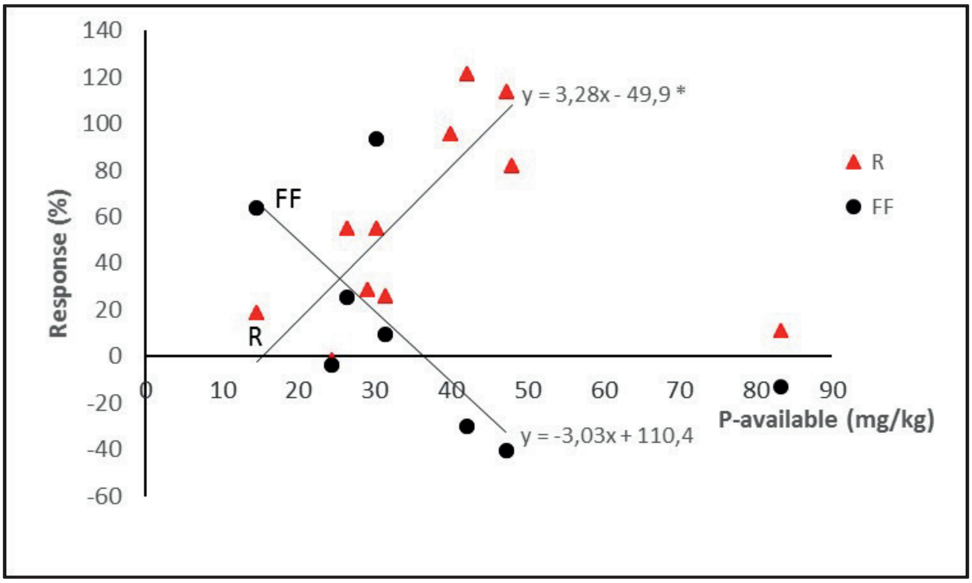

Figure 6.4: Response of wheat for recommended application of fertilizers (R, 100 kg DAP/100 kg urea) and on adjacent farmer fields (FF) in relation to P-available (*R-squares* for FF and R were respectively 0.47 and 0.69; * = significant at p=0.05).

Relating fertilizer response of wheat to soil properties, in this case P-available, showed in the lower range (below 50 mg/kg) a positive correlation for the overall response of recommended application of fertilizer. For farmer fields, on the contrary, negative correlation between P-available and response was observed in the lower range (Fig. 6.4). In both cases, outcomes for one specific highly fertile soil (Machalawi homestead soil) did not fit very well with the linear trend observed for the lower range of P-availability and instead pointed to quadratic relationships. Absolute response of recommended application was low and only in four out of eleven cases exceeded 1000 kg/ha (Fig. 6.5).

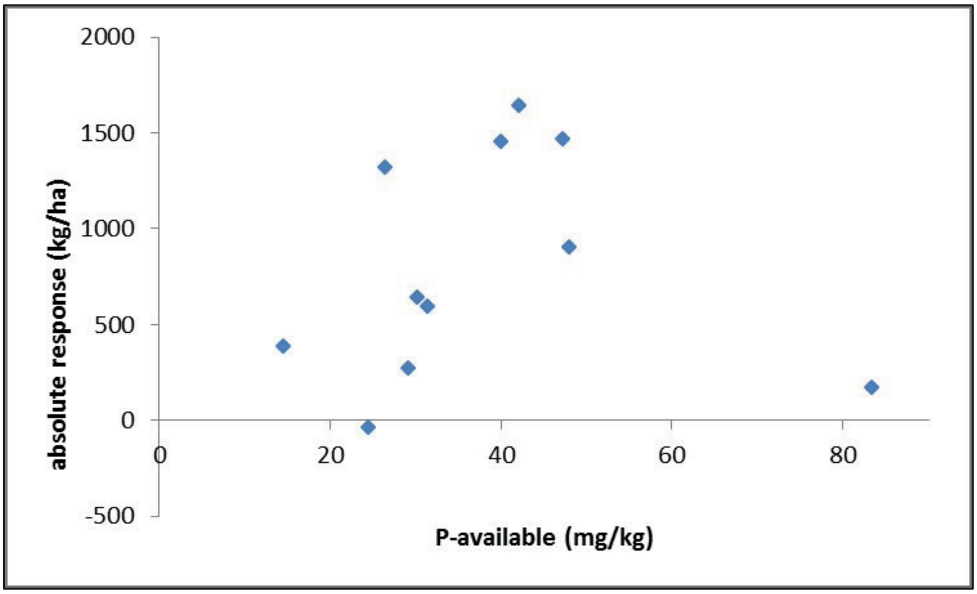

Figure 6.5: Absolute response of wheat for recommended application of fertilizer (100 kg DAP/100kg urea) in relation to P-available.

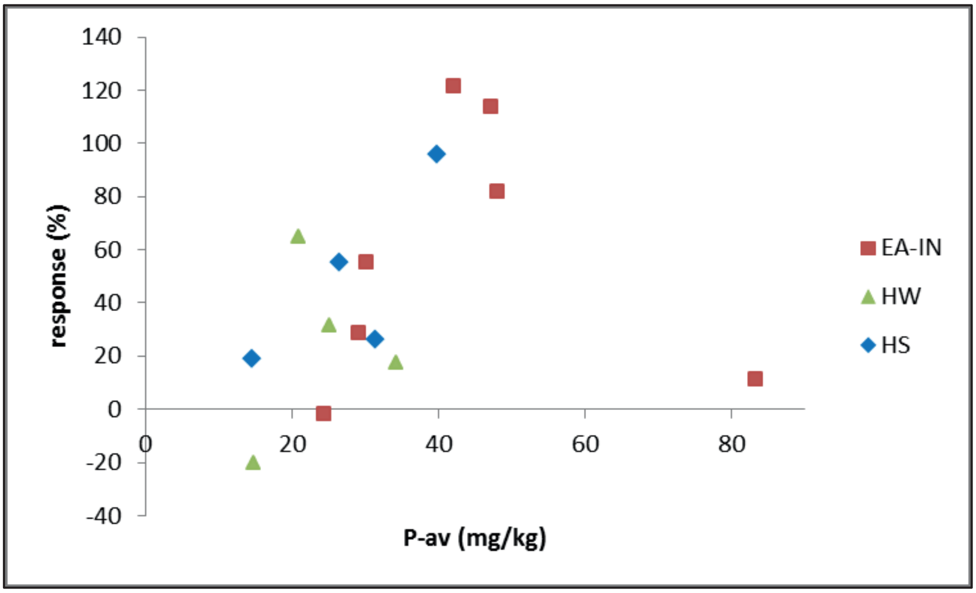

Figure 6.6: Response of wheat contrasted for different landscapes in relation to P-available (P-av). EA-IN = basalt highlands of 2000-2300m, HW = sandstone/shale highlands of 2000-2300m, HS = basalt highlands over 2300m. Differences were not significant (p= 0.44).

Differences in response between the three main landscape type were limited and not significant (Fig. 6.6). The trend observed is very comparable to Fig. 6.4, and the additional sites from Hawzen, despite their lower recommended rate of fertilizer application, fitted in this trend.

The agronomic use efficiency, which in our case was based on N-input, correlated with P-available at lower levels only (Fig. 6.7). This implied that use efficiency and response were better on the better soils. Differences between two levels of N-input (64 and 41 kg N) were not significant (p = 0.90).

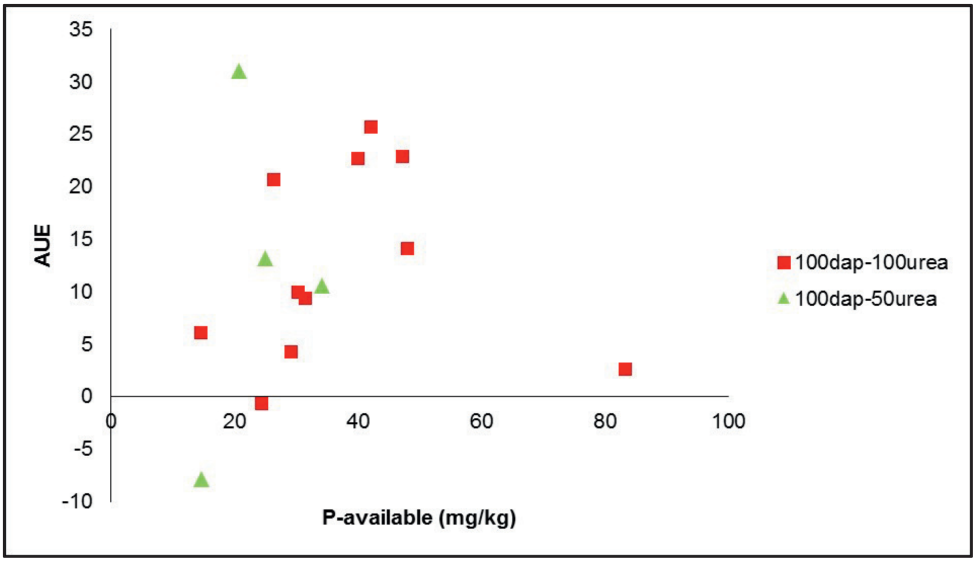

Figure 6.7: Agronomic Use Efficiency (AUE) of recommended fertilizer application related to P-available.

6.4 Discussion

6.4.1 Farmer Perspective

Farmers might observe that their current practices performed reasonably well as compared with recommended practice. The absence of significant differences between farmer fields and recommended application supported this. Farmers therefore are not likely to change current practices and will restrict themselves to small changes in management without investing much more in fertilizers. Our field observations showed that most farmers presently apply about a quarter of the quantity recommended, which is about 50 kg/ha of DAP and urea together, which somewhat matches with their economic capacity.

In 2014, the cost of the recommended 200 kg of fertilizer equaled the price of 500 kg of wheat. When considering risk in relation to fertilizer use, a rule of a thumb indicates that the value-cost ratio should be above two to be attractive for farmers (Donovan et al., 1999; Sharma, 2002). To cover cost and risk of recommended application of fertilizers (100 kg/ha DAP and 100 kg/ha urea) in our case required an increase in yield of wheat of about 1000 kg or more, a response that was not observed very frequently.

On the basis of our observations, we found a negative trend for farmer field response in relation to soil-P. This contrasted with the positive trend found for recommended application. This meant that farmers apparently did not invest much in nutrient-inputs on richer soils and instead seemed to prefer investments in the poorer soils. This might be motivated by a fear for lodging or a limited capacity to invest in all soils equally.

During our work with the farmer groups, we were surprised by their appreciation of high quantities of produced straw. This seemed related to the use of residues for livestock feed and the visual attractiveness of fields densely covered by straw bundles. This preference contrasted strongly with the usual focus of agronomists on grain productivity.

A potential pathway that farmers are likely to select, might be continuation of current practices (using manure and small amounts of fertilizers) and making, at the same time, small adjustments on the basis of continuous observation of productivity.

6.4.2 Agronomist Perspective

Soil analysis indicated that levels for N-total were low but for P and K in general satisfactory. Experimental outcomes, however, showed that responses of recommended fertilizer application and soil-P were positively correlated. Increasing productivity by applying fertilizers therefore seemed to be limited by available soil-P, especially in the lower range. Although our data did not cover the whole range of P-available, the incidence of non-responsive highly fertile (homestead) soil was still in line with observations made by Tittonell and Giller (2013). In our case, optimal application rates for fertilizers could not be defined because available data did not allow preparation of the required fertilizer response curves. Modified stability analysis indicated that productivity increased but that relative responses on the better soils decreased.

Economic returns of high application levels were in many cases disappointing. In 2014, the cost, expressed in Ethiopian Birr (ETB), of recommended application was about 40-50 ETB/kg N, selling 1 kg of wheat brought about 5 ETB. This meant that the agronomic use efficiency should be at least around 8 to 10 to cover the cost. Including risk would even require an agronomic use efficiency of around 20. Such high values were, as was the case with value-cost ratios, most of the times not reached.

Application of high rates of fertilizer resulted in improved productivities; as a consequence of the improved productivity, removal of nutrients also increased. The application of recommended fertilizer rates apparently led to negative nutrient balances, which was in line with the findings of Abegaz et al. (2007). Sustainability, as expressed in closed nutrient balances, is therefore difficult to achieve.

Manure treatments in this respect scored better; lower productivity levels and returning nutrients contained in crop residues were responsible for this. Nutrient balances for manure clearly demonstrated the important role of the livestock component in mixed farming systems in relation to sustainable nutrient balances.

Potential pathways from this perspective include the application of P-containing fertilizer (i.e. use more DAP instead of urea) in low P-soils, using high amounts of fertilizers to close nutrient balances, however, without achieving optimal economic benefits. The use of manure and legumes without a primary focus on highest yields seemed promising in farming systems under relatively marginal conditions. The much promoted ISFM is an example of this.

6.4.3 Environmentalist Perspective

Taking a long-term perspective revealed that contradiction existed between the persistent negative nutrient balances as found in literature (Haileslassie et al., 2005; Stoorvogel et al., 1993) and the existence of agricultural systems that remained almost unchanged for over 2500 years, suggesting at least some degree of system stability.

Full nutrient balances calculated from our experiments and by using data from Haileslassie et al. (2005), were negative for the controls and recommended treatments, which suggested a severe risk for long-term nutrient depletion. Legume fallows and manure, both important components of current and probably also historical farming systems, resulted in more sustainable nutrient balances.

Major uncertainties in our long-term calculation were climate and landscape development which related to erosion and sedimentation, two important components of the nutrient balance. In addition to this, differences between specific nutrients are relevant too. Depletion of soil-N, of which the stock depends on soil organic matter, is, for example, more likely to be affected by erosion than soil-P, which is also contained in soil minerals. In the full balance, the aspect of weathering is not included. However, this might be important in the context of shallow soils on relatively rich basaltic and sedimentary parent materials. The same holds true for the likely incidence of deposits of volcanic ashes from the nearby Danakil region.

The long-term nutrient balance calculated seemed to justify the claim of historical sustainability. On the basis of this, a pathway can be identified that takes full advantage from the mixed farming system by using manure to import and recycle nutrients, securing N-inputs by including legumes and reducing outputs by aiming at moderate productivity. For example, by including *teff*, which acts as a semi-fallow, in the rotation. Occasional crop failure (or disaster fallow), will limit nutrient removal but still removes more nutrients than ordinary fallow and is as such not instrumental in achieving sustainable long-term nutrients balances.

6.4.4 Synthesis

Taking different perspectives meant that, on the basis of same set of experimental data, different interpretations could be deduced. Evidence for validity of each of these interpretations was found in the experimental outcomes and in the field observations made. In a next step, different associated pathways to transition could be proposed on the basis of each of these interpretations.

Combining these different interpretations revealed that:
(1) Systems using manure (and thus crop residues) appeared advantageous because of having slightly positive nutrient balances. Situations in which crop residues were removed, at the other hand, had dramatically negative balances, even in the case of fertilizers being applied. This indicated that the sole application of fertilizers will not by default improve nutrient balances and consequently even might result in less sustainable systems.
(2) The common combination of manure and fertilizer appeared optimal with respect to maintaining a stable soil fertility, especially when upgraded by using legumes and fallow periods that might compensate for depletion occurring during cropping years. Productivity levels of current farmer practices tended to be slightly lower than that of (recommended) application of fertilizers at high rates. Scores with respect to People-Planet-Profit-sustainability, however, were better.
(3) Farmers appeared, in line with this, to restrict themselves to close-to-current practices and will likely continue to do so, being actually bound by concerns of profit (economic returns) and people (food security) within the People-Planet-Profit-framework.

Our analysis of different perspectives suggested that in our study area, local farmers mainly will consider transitions with low risk. Such preferred transitions, however, still share essential elements with transitions having a more agronomist or environmentalist signature. Addressing specific farmer concerns (e.g. risk avoidance), when proposing pathways to sustainable development, therefore not necessarily excludes concerns of agronomists and environmentalists.

6.5 Conclusion

Different perspectives resulted in different interpretations of available data. Different answers to different questions were given and as such they complemented and to some extent supported each other. In our case, perspectives of farmers, agronomists and environmentalists were embedded in the People-Planet-Profit-framework, and merging these three perspectives resulted in a more coherent picture of the experimental outcomes that allowed defining pathways addressing sustainability in an adequate and convincing way.

Data were as such not a neutral entity but part of a specific constellation that included both data-set and perspective. This combination of data and perspective finally determined interpretation and meaning of the data considered. Making use of such different constellations in development context will result in more meaningful interpretation of data and in the identification of more optimal derived pathways to transition. In processes where stakeholders with different perspectives co-operate, it is therefore important to be aware of the possibilities of such multi-perspective analyses and to make use of them.

Acknowledgements

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7 Considering change: Evaluating four years of participatory experimentation with farmers in Tigray (Ethiopia) highlighting both functional and human-social aspects

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Abstract

Participatory approaches are advocated as being more effective in supporting rural development processes than traditional top-down extension approaches. Participatory experimentation involving both farmers and researchers are often expected to result in processes of experiential learning. Assuming that such learning leads to change in farmers' views and practices, we wanted to identify these changes. For that purpose we applied an analytical framework that included three dimensions (process, outcomes, impact) and functional as well as human-social aspects. We involved farmers in group-based participatory experimentation for four years with minimum external intervention, aiming for maximum control of the experiments by the farmers themselves. In total 16 groups of farmers distributed over four locations participated. Data were derived from interviews and observations. In general, participants considered their participation worthwhile and mostly valued learning-aspects. Farmers indicated that they had acquired new knowledge and had become confident with respect to specific agricultural practices such as fertilizer application. They also felt more confident in conducting systematic experimentation. This confidence was supported by the positive yield responses, over 50% in most cases, farmer groups had achieved. Participating farmers responded significantly different after the four years of experimentation compared to a control group of local farmers. After the four years they would: (1) involve non-family more in their discussions about farm management; (2) address officials more easily to solve neighbourhood problems; (3) be more specific in their ambitions to learn about agriculture. Participants perceived significantly more (positive) change towards productivity and poverty reduction compared to the control group. In contrast to our initial expectations, all groups continued their involvement in the experiments for four years and indicated the ambition to continue on their own. Of a set of factors that might influence involvement of farmers, only benefits in the form of good responses were overall important. All other factors were highly variable among the groups. We concluded that change was achieved with respect to functional and human-social aspects, which are both essential components of agricultural systems and affect their transformation. In designing processes of participatory experimentation it is, therefore, important to take such non-uniform sets of impact factors into careful consideration. Given the diversity of groups and the context in which they operate, blue-print approaches

are not likely to be effective due to insufficient incorporation of local group variability.

7.1 Introduction

Participatory approaches are advocated for being more effective in supporting rural development processes than traditional top-down approaches often used by extension services (Biggs, 2007; Chambers and Jiggins, 1987b; Ellis and Biggs, 2001). Such participatory approaches involve farmers – together with researchers or practitioners – and are often referred to as a process of joint experiential learning. Examples of such participatory approaches are the Farmer Field School (FFS) approach (Braun et al., 2000; Duveskog et al., 2011; Misiko, 2009), Participatory Extension Approach (PEA) (Hagmann et al., 1998), Participatory Learning and Action Research (PLAR) (Defoer, 2000), and more recently Participatory Innovation Development (PID)(Scogings et al., 2009).

Whether all participants really learned during and as a result of the participatory process is difficult to assess. This is because learning processes and evidence for learning are for multiple reasons difficult to grasp (Boyd et al., 2006; Dienes and Altmann, 2003; Kraaijvanger and Veldkamp, 2017; Prince, 2004). This holds even more in a context where language and cultural barriers hamper effective communication. Evaluation of resulting empowerment, contribution to development processes and impact on farmers' livelihoods is equally or even more complex (Barrera-Mosquera et al., 2010; Misiko, 2009; Trimble and Lázaro, 2014).

Farmers often have multiple reasons to be involved with researchers and practitioners, and these motivations need not necessarily be directly aimed at the improvement of their knowledge and skills. Participation, for example, can also be driven by incentives such as free seeds and fertilizers or access to credit (Mapfumo et al., 2013; Probst, 2002). Other perceived benefits can relate to having contact with outsiders, e.g. access to knowledge and social status. External material and cognitive inputs need to be reduced to a minimum as they might lead to dependency, which hampers sustainability of participatory processes (Islam et al., 2011). Consequently, process inputs need to be restricted to facilitation.

In this chapter we explore the complex interactions between process, outcomes and reported impact in the context of participatory experimentation with farmer groups in Tigray, northern Ethiopia. In addition, implications for the use of participatory approaches in agricultural rural development are discussed. From

2009 to 2014 we were involved in group-based participatory experimentation with 16 groups of about five farmers in Tigray.

Incentives other than those based on learning and interaction from participatory experimentation were deliberately reduced to a minimum. From the start on and throughout the process we systematically monitored participating farmers through a series of interviews and observations. Furthermore, all participants as well as a control group of randomly selected comparable farmers were interviewed on aspects relating to attitude and cognitive ability at the start (baseline interviews) and the end (final interviews) of the process and questioned about perceived livelihood changes during this period.

Changes in attitude and livelihoods of farmers involved in participatory experimentation can be evaluated using three interrelated dimensions: (1) process; (2) outcomes; (3) impact/change (Blackstock et al., 2007; Fazey et al., 2014; Hassenforder et al., 2015; Trimble and Lázaro, 2014). Douthwaite et al. (2003) indicated that from a constructivist perspective monitoring impact of participatory approaches requires considering two aspects: (1) direct benefits and (2) wider livelihood and developmental changes. Duveskog et al. (2011) referred in line with this to instrumental knowledge and collective/individual agency as important outcomes in the context of Farmer Field Schools. Also Hellin et al. (2008) used a similar division and referred to respectively functional aspects and empowerment.

Both functional aspects (e.g. crop yield, technology) and human-social aspects (e.g. knowledge, co-operation) represent important components of agricultural systems. An analytical framework based on the above dimensions (process, outcomes, impact) and aspects (functional, human-social) was used to analyse farmer-reported changes. We combined this with our own observations on obtained crop yield, efficiency of use of inputs and the use of novel technologies.

Three research questions guided our analysis:

1. What changes relating to functional and human-social aspects became explicit over the four years of participatory experimentation?
2. Can these changes be linked to the involvement in the participatory experimentation?
3. What motivated participants to stay involved?

7.2 Methods

7.2.1 Process

Farmer groups were involved for four years in a participatory experimentation pathway based on four experiential learning cycles of experience-design-experimentation-reflection (Kolb, 1984). Elements of the research cycle focusing on implementation of novel technology as described by Giller et al. (2011) were also manifest: farmers started with sessions in which description (constraints and context) and exploration (opportunities) were covered. We started the process in 2009 by involving 16 groups of farmers in four locations, with four groups for every location. These groups (each of about five farmers) were deliberately composed of neighbouring farmers. We assumed that in doing so a long term co-operation would be more feasible, connections with the communities would be secured and logistic constraints would be reduced.

Additionally, interviews were conducted with a control group of about 65 farmers. These farmers were selected randomly using administrative lists at *tabia*-level and came from the same locations as the involved participants. Information on the locations is presented in Kraaijvanger and Veldkamp (2015b) and Kraaijvanger and Veldkamp (2017). All experiments were designed by the farmers themselves and conducted on-farm. Annual workshops and field visits were organized to design and evaluate the experiments.

Our research was framed as participatory experimentation, and can be called a *collegial* type of participation in the terminology of Biggs (1989). On the scale proposed by Pretty (1995) the description of *interactive participation* best matched our situation. In fact, we chose an even more extreme position, aiming at a *research context with less direct intervention* (Okali et al., 1994), since control over the experimentation process was almost fully delegated to the farmers. Therefore, our inputs were reduced to a minimum and we focused on overall facilitation of the process. Next to avoiding bias due to differences in interventions from our side, we also expected in doing so to promote commitment of the farmer groups and to avoid interference by external agendas.

Our inputs, therefore, were restricted to facilitation of the experiments and including, in addition to the treatments the farmer groups proposed, alternative treatments. This was done for purpose of comparison (controls and current practice on farmer fields), achieving some experimental rigor (replications) and inspiration (Arévalo and Ljung, 2006; Sumberg et al., 2003). Alternative treatments were included in the experimental lay out only when possible (the maximum number of plots was about 15). Farmer groups evaluated all treatments and had the mandate to in- or exclude these from the experiments.

7.2.2 On-farm experimentation and management

Experiments were conducted on-farm using fields that were selected by the farmer groups themselves. In most cases fields hosted the experiments for more than one year. The responsibility to implement the experiments was taken by the owner of the field. Accordingly, most discussions on experimental management took place with him or her. The experimental fields in most cases contained blocks with 15 plots of 3.0 m x 3.0 m. On each plot a specific treatment was applied. More information about the experimental set up can be found in Kraaijvanger and Veldkamp (2015b).

In each experimentation year from our side specific treatments, such as sowing in rows, were included in the design in order to evaluate if such treatments would be adopted later on. Our inputs in the experimentation itself were restricted to delineation of the plots, establishing control plots, application of measured quantities of mineral fertilizers, manure and compost, and harvesting the crop in order to obtain exact and reproducible yield data. Field management like weeding and crop protection was the responsibility of the farmer groups. Yield data were presented to the farmers immediately after the harvest to support discussion among the farmer group prior to the workshops. In the final phase of our participatory experimentation, we delegated more responsibilities to the farmer groups and challenged them in 2013 to harvest part of the experimental plots themselves and in 2014 to continue their experimentation after termination of our involvement in April 2014.

7.2.3 Workshops

An important component of our research project consisted of conducting workshops with farmer groups. These workshops formed the main platform for discussions on experimentation and were conducted every year. The topic of discussion of the first workshop was constraint and opportunity identification (see Kraaijvanger et al. (2016a)). The outcomes of the first workshop were analysed and served as an input for the other workshops. All following workshops dealt with the outcomes of on-going experimentation and the preparation of experimental designs based on these outcomes, covering in this way the reflection-experience-design phases of the experiential learning cycle (Kolb, 1984).

During the workshops group members discussed among themselves, but also exchanged ideas with other groups in plenary sessions. When farmers participated in the workshop, they obtained, in line with the regulations of the Bureau of Agriculture and Rural Development (BoARD), a *per diem*. This covered for hiring field labour to replace them. In addition also a lunch was provided.

7.2.4 Individual surveys and interviews

Individual surveys and interviews were divided in three sets:

- Set 1: Individual surveys on livelihood changes (in retrospect) with participants and a control group (in 2013).
- Set 2: Baseline interviews (in 2010) and final interviews (in 2013) with participants and a control group on attitude and cognitive ability.
- Set 3: Two series of surveys with participants on benefits resulting from involvement in participatory experimentation (in 2013 and 2014).

In all surveys and interviews the same translators were involved. The control group involved in the individual surveys and interviews of set 1 and set 2 was the same and consisted of individual farmers that were not involved in our participatory experimentation. Respondents of the control group came from the same neighbourhoods as the participants and were selected randomly from administrative lists at *tabia*-level. Questionnaires were prepared in collaboration with the translators and tested and improved based on first experiences. The individual surveys of set 1 resulted in direct (quantitative) outcomes, interview responses of set 2 and 3 interviews were first categorized and relative frequencies of these outcomes were calculated in order to allow comparison. However, not all questions and responses were included in our assessment: a selection was made based on relevancy.

Set 1: Individual surveys on livelihood changes

Chambers and Conway (1992) and later on also Bebbington (1999) and Mancini (2006) forwarded and applied the concept of seven different capitals (human, political, cultural, social, physical, natural, financial) representing the livelihood status of farmers. Since changes in livelihoods are often related to the capitals that constitute these livelihoods, we defined, in line with Cosyns et al. (2013), a set of indicators based on the concept of capitals. These indicators referred to a specific sub-set of the so-called sustainable livelihood capitals (Chambers and Conway, 1992) and included financial, natural, social and human capital (Table 7.1). Physical capital was not included since we considered it far outside the main scope of our participatory experimentation. The learning aspects of human capital were dealt with in interviews and surveys of set 2 and 3.

Based on the indicators seven straight-forward questions were prepared. Participants and control group farmers indicated in response to these questions the status of specific livelihood aspects by attributing scores on a Likert scale from 1-10, first for the present and then in retrospect for the past situation (five years ago). Attributing scores was explained to the respondents by using a small chart with numbers. In total 133 farmers (74 participants and 59 control group farmers) were questioned. The score for the past situation was subtracted from the score for the present situation to determine whether or not respondents perceived positive change (progress) in their livelihood over the last five years. Differences between participants and control group farmers were evaluated by using Chi-square-test. Outcomes of this retrospective served to document farmer-reported change in livelihood capitals.

Table 7.1 : Overview of livelihood aspects and corresponding capitals.

Aspect	**Livelihood capital**
Personal economic situation	Financial
Poverty in the neighbourhood	Financial
Productivity of the land	Natural
Co-operation in the neighbourhood	Social
Health situation	Human
Occurrence of soil erosion	Natural
Presence of trees and bushes	Natural

Set 2: Baseline interviews (2010) and final interviews (2013) on attitude and cognitive ability

The baseline and final interviews constituted of a set of eleven indirect open-ended questions and focused in eight questions on attitude related aspects, the remaining three questions dealt with cognitive ability (for the full sets see Kraaijvanger (2015a)). By conducting the baseline and final interviews we aimed at capturing differences in relation to attitude and cognitive ability over the period of involvement and between participants and non-participants. These structured interviews were designed in such a way that in both series the same aspects were addressed by either repeating questions or by slightly altering them. Responses to these questions were categorized and used to derive trends in responses of the control group between 2010 (n=66) and 2013 (n=60), of the participants between 2010 (n=78) and 2013 (n=76) and to compare between the participants (n=76) and the control group (n=60) in 2013. Differences between interview outcomes were evaluated by using Chi-square-test.

Set 3: Individual surveys on benefits resulting from involvement.

Two series of surveys with participants were conducted to identify what benefits they perceived from their involvement. In 2013 participants (n=78) were asked four open-ended questions to indicate the most important benefits of their involvement in participatory experimentation. In 2014, during the final workshop, the participants (n=76) again responded to two open-ended questions relating to their involvement in participatory experimentation. We inductively grouped responses to these questions into categories with specific concerns based on similarity of expression. Frequencies found for these categories served as an indication of farmer-reported benefits resulting from their involvement in participatory experimentation. Outcomes, therefore, informed us about the relation between involvement and benefits, and about farmers' motivation for staying involved.

7.2.5 Selection of experimental treatments

Changes in type of experiments selected by the farmers were assumed to be related to changes in attitude and skills. The type of treatments that farmers defined therefore were categorized and analysed. We defined inductively five categories that captured aspects of novelty and tradition. These aspects reflected the preference for specific treatments of farmer groups (see Table 7.2). Each cycle of experimentation we scored the frequency of treatments in each category.

Table 7.2: Overview of defined categories of experiments.

Category	**Treatments**
Traditional	compost, manure or compost+manure
Recommended	Urea (= N-fertilizer) +DAP* (= N & P fertilizer)
Experience/advanced practice	combinations of mineral and organic fertilizer
"Out of the box"	DAP* (only), urea (only), application rates, control, ash, fallow-effect, farmer field
Introduced **	Applying potassium (K), row sowing, opening subsoil

Box 7.1: Factors explaining motivation and involvement in participatory experimentation

External factors:

External factors represent the impact of policies of governmental or non-governmental organisations (NGOs) on the life-worlds of the farmers (Hailu, 2009; Klerkx et al., 2009). Criteria we considered were past and present impact of NGOs and BoARD in supporting farmers (for example, by providing incentives and facilities) and were based on interviews with various informants.

Group quality:

Group quality is a broad notion in which we tried to capture various aspects that might be relevant for the functioning of groups. The criteria we considered were leadership, composition (age, gender), coherence and the use of existing structures. The criterion of leadership (Hailu, 2009; Islam et al., 2011; Ndekha et al., 2003) was assessed based on interviews with participants. If three or more group members (out of five) indicated a specific person to be their leader we considered this unanimous. Age and gender (Probst, 2002) were included to cover the aspect of heterogeneity; we assessed this by considering the presence of women and young farmers (age under 35) in the group. Both being present in the group resulted in a positive score. Coherence and using existing informal networks (Marquardt et al., 2009) were scored by using observations on a casual basis.

Benefits:

Direct and indirect benefits of involvement might provide, under the assumption of rational behaviour, motivation for participants (Ndekha et al., 2003). We used yield responses of farmer-selected treatments as a proxy for such benefits and to that end considered average response of the *"best-three"* treatments (as selected by the group) during the last three years of our investigation. We excluded the first year because at that time no experiential learning was yet involved in selecting the experimental treatments. The categories were defined as being below and above 50% yield response as compared to the control plots (see also (Kraaijvanger and Veldkamp, 2015b)).

Institutions:

Institutions represent the formal and informal setting in which the farmers operate and are considered very important in supporting participation (Arévalo and Ljung, 2006; Dienes and Altmann, 2003; Prince, 2004). Such settings can be either productive or contra-productive (Van Rijn et al., 2012). In our evaluation we assumed embedment of the groups in their communities to be a positive factor since responsibilities in that case are expected to become more pronounced. The overall evaluation of this embedment was based on personal observations. Criteria that we included were: presence of local administration leaders, participation of *keshi's* (priests), interest in group activities (for example, through expansion with new members) and accountability towards the community (for example, by taking explicit responsibility for the experimentation).

Facilitation:

Facilitation of the groups is very important in relation to motivation. This was assessed by considering to what extent field assistants were involved in co-operating with the groups.

7.2.6 Factors motivating involvement

Based on literature (Hailu, 2009; Hall et al., 2006; Islam et al., 2011; Klerkx et al., 2010; Marquardt et al., 2009; Misiko, 2009; Ndekha et al., 2003; Poteete and Ostrom, 2004; Probst, 2002; Van Rijn et al., 2012; Wenger, 2000), we defined a set of factors that were assumed to have impact on the involvement of participants in group-based processes: external factors, group quality, resulting benefits, institutions and facilitation. The effect of these factors was monitored by using specific criteria that matched with our context (see Box 7.1).

Various sources of information were used to evaluate the impact on involvement, ranging from interviews and calculated data on yield responses to participant observations on how specific groups functioned. Participant observations were made not only in official meetings like workshops and field visits but also in interactions on a more casual basis, for example, at harvesting. We also included observations from our field assistants and interpreters. In our qualitative assessment we used only 2 categories: 0 (= standard) and + (=above standard) for every criterion. Outcomes of this assessment were used to identify possible motivations for involvement of farmers in participatory experimentation.

7.2.7 Analytical framework

To systematize our evaluation of how functional and human-social aspects changed, we included characteristic elements of the participatory experimentation method applied, in our analytical framework and made reference to their respective data sources (Table 7.3). Specific examples of functional aspects relating to the three dimensions of our framework (i.e. process, outcomes and impact) are respectively systematic experimentation, measured yield response and change of natural livelihood capital. As examples of human-social aspects respectively participation, obtaining skills and change of social capital can be mentioned. Since strict criteria for evaluation cannot be provided beforehand, we used in our assessment an inductive approach.

Table 7.3: Analytical framework based on dimension (process, outcomes and impact) and aspect (functional and human-social) with specific elements of our participatory experimentation method included.

Dimension	Functional aspects	Human-social aspects
Process	systematic experimentation	participation (lists)
	mandate for experimental design with the farmers	gender representation (lists)
	Availability of quantitative yield data	power relations (participant observation)
	On-farm experimentation	leadership (participant observation)
Outcomes	treatment responses (measurements)	attitude (surveys set 3, participant observation)
	treatment selection (lists)	skills (surveys set 3, participant observation)
Impact	natural capital (surveys set 1)	human and social capital (surveys set 1)
	Technology adoption (participant observation, surveys set 3)	attitude (interviews set 2, participant observation)

7.3 Results and Discussion

7.3.1 Individual surveys and interviews

7.3.1.1` Individual surveys on livelihood changes (2013)

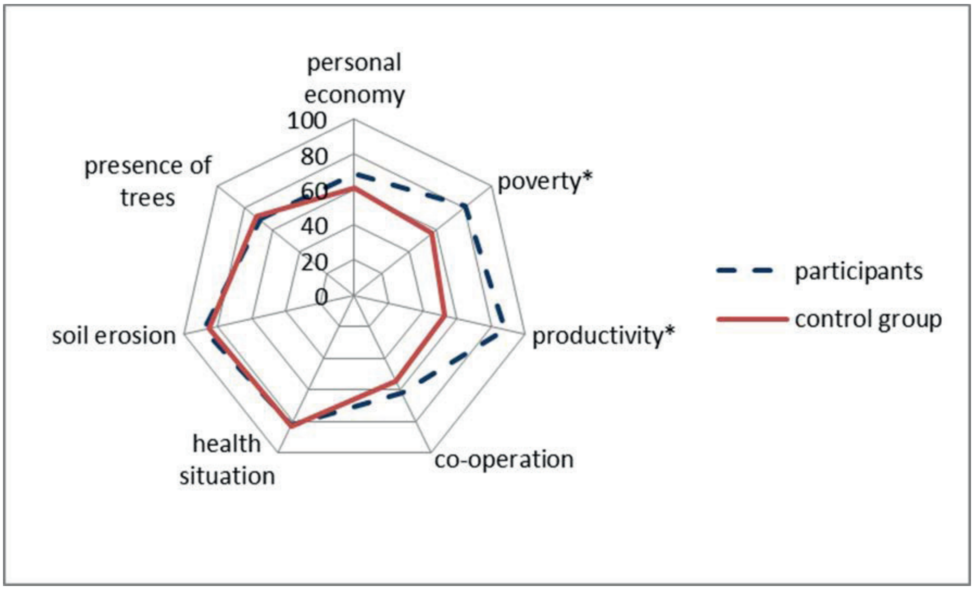

Figure 7.1: Improvement of livelihood aspects between 2009-2013 (in %) as perceived by participants (n=74) and the control group (n=59). Significant difference with control group (Chi-square, p=0.05) is indicated by an asterisk (*).

The retrospective outcomes showed a trend that participants reported more positive change in their livelihood for the last five years in comparison to control group farmers. These positive changes concerned the aspects of co-operation, poverty, personal economy and productivity (Fig. 7.1). Considering the fact that the experimentation directly dealt with group participation and impact on crop productivity, the relation between participation and perceived positive change appeared to be causal. The remaining set of livelihood aspects (health situation, occurrence of erosion and presence of trees and shrubs) did not differ much between participants and control group farmers. Not surprising, as occurrence of erosion and presence of trees and shrubs were outside the direct scope of our experimentation. Also health situation was considered relatively constant, mainly because scores attributed were in most cases close to the maximum for both past and present and most likely reflected effective (governmental) policies to improve the rural health situation.

7.3.1.2 Baseline and final interviews on attitude and cognitive ability (2010 and 2013)

Only four out of the original eleven interview questions revealed relevant differences, either over the four years or between control group and participants (see Table 7.4). The other seven questions resulted in indifferent, non-discriminating outcomes. All three questions relating to cognitive ability resulted in highly variable outcomes, most likely because these questions were, in retrospect, too complex and context dependent. Of the remaining eight questions on attitude the questions dealing with *"co-operation"*, *"causes for poverty"*, *"giving advice to colleagues"* and *"actions taken to improve crop productivity"* also resulted in variable outcomes that appeared to be more influenced by fixed ideas and views than by (non)involvement in participatory experimentation.

In *"solving conflicts"* (question no 1) participants were more ready to involve officials in 2013 (Fig. 7.2). *"Interaction with development agents"*, question no 2, showed an interesting pattern. Four years ago farmer-participants would not easily start a discussion with a development agent (DA). However, in 2013, they had, just like the control group farmers, become more outspoken and frank in their discussions. Both participants and control group appeared to have changed from somewhat obedient followers towards a more critical attitude. Providing an adequate explanation for this shift is, based on our data, difficult and different reasons can be provided. For example, increased knowledge and confidence on the side of the farmers or less dominance on the side of the DAs. With respect to *"involving outsiders for discussion"* (question no 3), participants increasingly engaged with officials, but the control group stopped completely doing so and on contrary started relying more on family members. The question on *"learning ambitions"* (no 4) revealed that both participants and control group were mostly interested in acquiring more agricultural knowledge. In 2013 significant more participants preferred to learn about specific agricultural topics in comparison to 2010 and in contrast to control group farmers.

Table 7.4: Questions and categorized responses used in our evaluation of social aspects. (Shaded responses are used in our comparison).

No	Question	Aspect covered	Response categories	Corresponding number of the response axis in Fig. 7.2	Example responses
1	What will you do to stop grazing of animals on your fields (Final interviews phrasing: What will you do to stop travelling through your fields?)	Changing attitude	Direct approach		telling him to stop
			Indirect approach		asking others to discuss
			Involve officials	1a	*tabia* police
			Allow		no problem
			Own action		fencing
2	What will you do in relation to the advice given by a development agent ?	Changing attitude towards officials	Discuss and reject	2a	
			Accept	2b	
			Reject without discussion	2c	

Table 7.4 continued: Questions and categorized responses used in our evaluation of social aspects. (Shaded responses are used in our comparison).

	Question	Aspect covered	Response categories	Corresponding number of the response axis in Fig. 7.2	Example responses
3	Mention 3 persons with whom you frequently discuss issues related to agricultural practice ?	Changing network	Family	3a	uncle; wife; son
			Friends/neighbours	3b	
			Officials	3c	development agent (DA); tabia administrator
4	What would you like to learn ?	Personal reflection	Formal education		reading; writing
			General agriculture		becoming productive
			Specific agriculture	4a	beekeeping; growing fruits
			Specific non agriculture		nursing
			Nothing	4b	"I am too old"

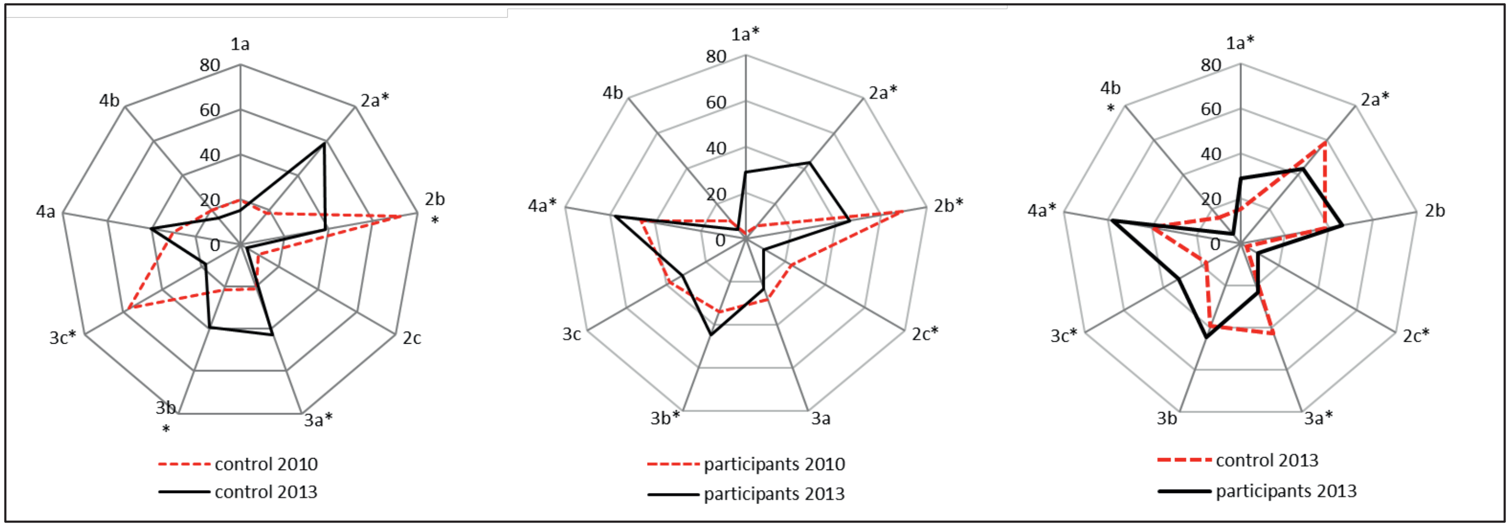

Figure 7.2: Categorized responses (%) of: control group farmers in 2010 (n=66) and 2013 (n=60); participants in 2013 (n=76) and 2010 (n=78); participants (n=76) and control group farmers (n=60) in 2013. Responses refer to 4 questions: (no 1) "attitude in relation to solving problems" (corresponding response: (1a) "involve officials"); (no 2) "discussion with extension workers" (corresponding responses: (2a) "reject with discussion, (2b) "accept", (2c) "reject without discussion"); (no 3) "discussion on agricultural issues" (corresponding responses: (3a) "with family members", (3b) "with neighbours and friends", (3c) "with officials"); (no 4) "on learning ambitions" (corresponding responses: (4a) "specific agriculture", (4b) " nothing"). Significant difference (p = 0.05) between groups is indicated by an asterisk (*).

7.3.1.3 Individual surveys on benefits resulting from involvement (2013 and 2014)

There was much repetition in the issues farmers mentioned in response to our questions. Participants often made reference to project related technologies. In other cases, however, participants referred to specific technologies that were not directly related to the project (Table 7.5). Other recurrent responses related to human-social aspects (sharing ideas, co-operation).

In evaluating their involvement (question 1) farmers rated gaining knowledge as being important (Fig. 7.3). When looking more specifically into the way farmers evaluated benefits of their involvement (question 4) we observed that acquiring specific technical knowledge and sharing ideas were considered important by them.

One farmer commented on the issue of obtaining knowledge: *"We got a clear understanding of fertilizers and manure but the most important gain is that we now know how to do research by ourselves, although it is not scientific."*

The knowledge obtained can be related to both project and non-project sources and possibly resulted in a change of agricultural practices during the last five years. Clear project related issues were for example the adequate use of fertilizers and row sowing. Of the non-project specific matters, the use of selected seeds and irrigation was mentioned by the farmers. The use of selected seeds was by some farmers associated with the project. However, in a strict sense this did not apply since the farmer groups came up with this issue themselves.

Farmers often highlighted such technology related achievements: "*I did an experiment of sowing in rows, the difference was 2.5 quintal*"; "*Learning about selected seeds from the experiment brought change*"; "*I learned what the soil needs*".

When more specifically looking at co-operation (question 5), sharing ideas was considered important (Fig. 7.5). In an indirect view on their involvement (question 6) farmers frequently mention jealousy (on them) and the aspect of learning.

Farmers commented accordingly to their learning: "*You learn from each other a lot and from what you see in the experiment, it would be nice to try this also in our individual fields*"; "*We share ideas and add learning to our traditional* *knowledge which is passed to the young generation"; "We learned a lot and are ready to teach others"*

In general they assumed that outsiders perceived their participation to be worthwhile. Explicit financial benefits were only mentioned in few cases.

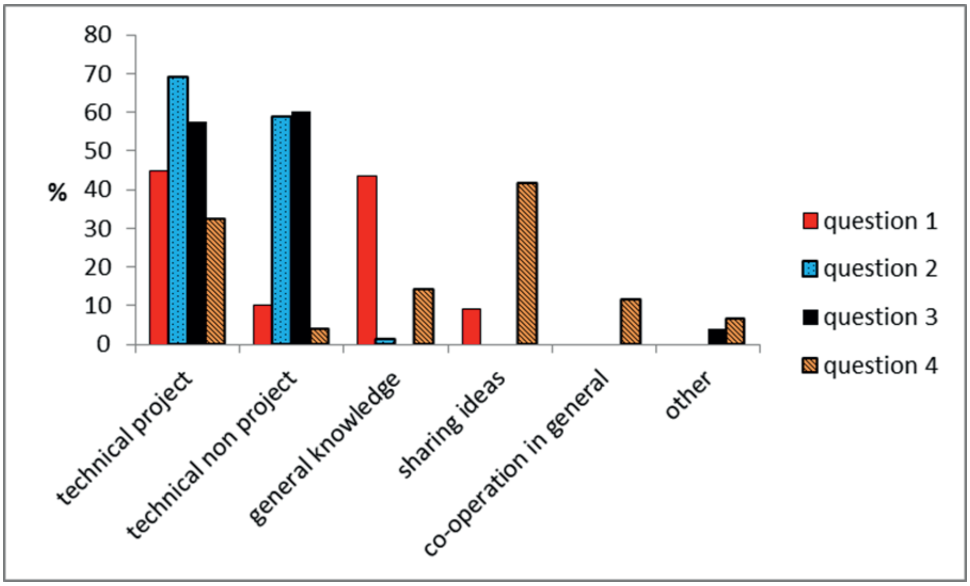

Figure 7.3: Categorized responses to questions relating to involvement in participatory experimentation (as a % of respondents, n=78 for all questions except n=76 for question 4). Responses refer to 4 questions: (1) "what was important in the project"; (2) "what did you learn about agriculture"; (3) "what practices did you change"; (4) "which were the benefits of being involved". Categories refer to the main concerns of the responses.

Table 7.5: Evaluation of involvement: response categories and examples.

No	Question	Category*	Examples
1	What was important with respect to the experimentation for you ?	Technical project knowledge (specific)	using compost; mixing fertilizers
		Technical non-project knowledge (specific)	using selected seeds
		General knowledge (non-specific)	gaining knowledge
		Sharing ideas (collectively)	sharing ideas
2	What did you learn the last 5 years with respect to agriculture ?	Technical project knowledge (specific)	use of fertilizer
		Technical non-project knowledge (specific)	terracing; selected seeds
		General knowledge (non-specific)	practical knowledge
3	What changed for you the last 5 years with respect to agriculture ?	Technical project related changes (specific)	use of fertilizer
		Technical non-project related changes (specific)	irrigation
		Other	becoming independent

Table 7.5 continued: Evaluation of involvement: response categories and examples.

No	Question	Category*	Examples
4	What was the most important benefit from being a member of the research group ?	Technical project related knowledge (specific)	learning to develop productivity
		Technical non-project related knowledge (specific)	constructing stone bunds
		General knowledge (non-specific)	getting education
		Sharing ideas	sharing ideas; "it is good to discuss about the experiments"
		Co-operation in general	helping other people if there is a problem
		Other	to be progressive; learning how to do research; understanding how to solve problems; getting payment

Table 7.5 continued: Evaluation of involvement: response categories and examples.

No	Question	Category*	Examples
5	What were benefits resulting from co-operating as a group ?	Sharing ideas	sharing ideas; learning from each other to select the progressive one
		Saving time	saving time
		Community	creating community, getting peace
6	How do others see you being involved in the research ?	Jealous	"Why are we not involved ?"
		Learning benefits	"They think we learn a lot"
		Financial benefits	"Some think we get a lot of money"

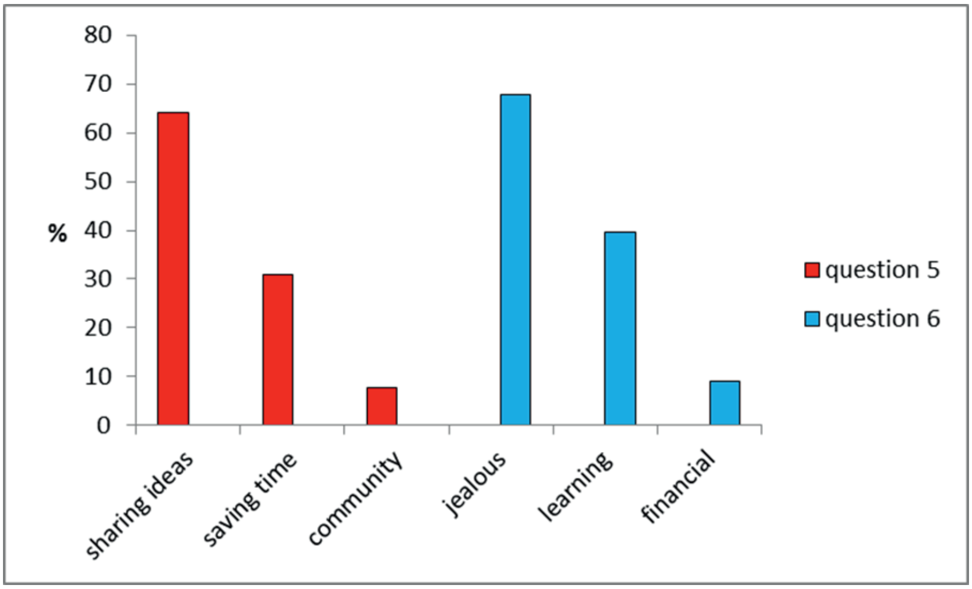

Figure 7.4: Categorized responses to questions relating to involvement in participatory experimentation (as a % of respondents, n=78). Categorized responses refer to 2 questions: (5) "what were benefits of group co-operation"; (6) "how do other people see your involvement". Categories refer to the main concerns of the responses.

7.3.2 Treatment selection

At the start of the research farmers selected mainly traditional and recommended treatments: 38 and 23 % of the experimental treatments fell in this category (Table 7.6). During the course of experimentation there was an increase in percentage of advanced practices (i.e. combination of treatments). An important change was that groups started including controls (data not presented), perhaps an indication that they learned and appreciated systematic experimentation. Initially groups adopted recommended and introduced treatments but left them out later. Interestingly, the inclusion of "out-of-the-box" treatments, such as the application of ash (Fig. 7.5), was relatively constant. Farmers indeed seemed to experiment with curiosity-driven treatments despite their unknown and therefore risky outcomes (Okali et al., 1994).

Table 7.6: Type of treatments as selected by the groups in the years 2010-2014.

Year	n	Traditional %	Recommended %	Advanced practice %	Out of the box %	Introduced %
2010	60	38.3	23.3	8.3	30	0
2011	200	19.5	19.5	11.0	32	18.0
2012	173	19.7	19.1	12.2	29.5	19.6
2013	209	12.4	14.8	18.1	28.7	25.9
2014	135	9.6	15.6	32.6	31	11.1

Figure 7.5: Out-of-the-box treatments in an experimental field in 2013: the whitish plots are treated with ash.

7.3.3 Factors motivating involvement in participatory experimentation

In contrast to our expectation that groups would over time become less committed because of limited material incentives from the project, we found that commitment persisted: after four years all 16 groups still were involved in participatory experimentation. Outcomes obtained in the experiments were considered important. The Inticho-groups, for example, mentioned that they considered out-scaling of findings essential and urged upon us the need of reporting these to BoARD-officials. In the final workshop (April 2014) all groups indicated that they would continue on their own and already had made decisions about the design and responsibilities for the experiments in the coming growing season. Out of 16 groups, in October 2014, about five months after our involvement had formally ended, 12 groups indeed had continued their group-experimentation. Of the four groups that not conducted an experiment in 2014, two indicated that they lacked facilitation. The two other groups indicated that they considered sorghum, which they planted in 2014 in most of their fields, not suitable for experimentation.

The results in Table 7.7 show that the only factor that was present in all but one group was perceived benefits (with yield responses for farmer-selected treatments above 50%). All other factors were distributed variable over the 16 groups and absence of a single specific factor (i.e. leadership, coherence, etc.) apparently did not lead to less involvement. Perceived benefits in the form of responsive treatments might thus have had an overriding importance in keeping the group experimentation going on. The other factors considered were either irrelevant, supported participation only occasionally or were compensated for by other factors present. In the final, informal, stage of our involvement, some farmers explicitly mentioned that facilitation was important for them in relation to their experimentation.

Table 7.7: Factors motivating involvement of the 16 groups of farmers over a period of four years, using different criteria (0 = standard, + = above standard).

Group	External factors	Group quality				Benefits	Institution	Facilitation
	NGOs, BoARD	leadership	coherence	composition	networks	Treatment responses (0=<50%; +=>50%)	Involvement local leaders; accountability; new members	Inputs field assistants
Tikuz	+	+	+	0	0	+	+	0
Adigudat	+	+	+	+	+	+	0	0
Endamariam	+	+	+	0	+	+	+	0
Munguda	+	0	0	0	0	+	0	0
Mymisham	0	+	0	0	0	+	0	+
Biherawi	0	+	+	+	0	+	0	+
Machalawi	0	0	0	0	0	+	0	+
Zonghi	0	0	0	0	0	+	+	+
Zalaweni	+	0	0	0	0	+	+	+
Mayzagra	+	+	0	0	0	+	+	+
Awadu	+	0	0	0	+	+	+	+
Siluh	+	+	+	0	0	+	+	+
Adikolagol	+	+	0	0	+	0	+	+
Dingelat	+	0	0	0	+	+	+	+
Adowro	+	+	0	0	+	+	+	+
Gudowro	+	0	0	+	+	+	0	+

7.3.4 Synthesis

7.3.4.1 Analytical framework

In the course of our research we collected and used different sources and types of information. To systematize our exploration of the relation between observed and farmer-reported change and involvement in participatory experimentation we included the outcomes of the interviews and observations in our analytical framework (Table 7.8).

This overview outlined in what way the dimensions of process, outcomes and impact and both functional and human-social aspects were interconnected and consequently allowed us to refine our exploration. Systematic experimentation was, for example, an important process component that enabled farmers to obtain experimental skills, which likely increased their confidence. In a similar way, the possibility for the farmers to include their own preferred treatments in the experimental design allowed them to use combinations of traditional and formal knowledge and to become more self-determined.

To arrive at a more integrated synthesis we first focused on the dimension of impact/change, which was relatively easily to monitor and then embarked on an explanation by considering the two remaining dimensions: the process in which the farmers were involved and the outcomes generated by this process. In addition, researcher experiences, functional and human-social aspects and implications for rural development processes were commented.

Table 7.8: Analytical framework including summarized research outcomes. Examples and data sources are included within brackets.

Dimension	Functional aspects	Human-social aspects
Process	systematic experimentation conducted (experimental blocks, controls, replications)	farmers kept participating (observed)
	experiments conducted within farmer fields	all groups continued (observed)
	exact yield data for grain and straw were collected	power relations: not clearly visible (observed)
	farmers used the available quantitative data (observed)	leadership was important for momentum (observed)
	farmers selected treatments according to their ideas (observed)	farmers operated as a group (observed)
		gender representation in the groups about 10% (observed)
		open and transparent process during workshops (observed)
		farmers considered their involvement worthwhile (farmer reported)

Table 7.8 continued: Analytical framework including summarized research outcomes. Examples and data sources are included within brackets.

Dimension	Functional aspects	Human-social aspects
Outcomes	adequate responses of specific treatments (measurement)	learning (farmer reported, observed)
	farmers selected effective combinations of treatments (observation)	farmers combined traditional and formal knowledge (observed)
	farmers rejected ineffective treatments (observation)	farmers were selective in using knowledge: they only used knowledge that was relevant
	farmers demonstrated experimental skills (observed)	co-operation (farmer reported, observed)
		learning (agricultural knowledge, experimental skills, farmer reported, observed)
		empowerment (farmer reported, observed)
		sharing ideas important (farmer reported)

Table 7.8 continued: Analytical framework including summarized research outcomes. Examples and data sources are included within brackets.

Dimension	Functional aspects	Human-social aspects
Impact	natural capital increased (crop productivity, farmer reported)	social capital increased (co-operation, farmer reported)
	using systematic experimentation (including controls, observed)	increase of knowledge and skills (farmer reported)
		increased confidence (farmer reported, observed)
	change in financial capital (less poverty, farmer reported)	farmers wanted to acquire specific agricultural knowledge (farmer reported)
		farmers expanded their networks (farmer reported)
		farmers became more self- determined in experimentation (observed)

7.3.4.2 Impact - What changes?

The results of this study pointed to a range of changes that took place in farmer-reported and observed attitude during the course of four years of group experimentation. Farmers indicated that they had gained knowledge and had become confident with respect to agricultural practices like, for example, the correct application of fertilizers in their fields. They also reported to be more confident in systematic experimentation. In line with this they indeed considered outcomes of previous years and included progressively more advanced treatments and controls.

Achieved crop yield responses of the selected treatments exceeded in most cases 50%, indicating that their selections indeed led to increased productivity. Over all groups we found for the period 2011-2013 responses for the *"best three"* farmer-selected treatments between 65-84 % and 32-52%, respectively compared to zero-input controls and current farmer practice on the same field (see for more details: Kraaijvanger and Veldkamp (2015a) and Kraaijvanger and Veldkamp (2015b)). In retrospect the farmers themselves also perceived an improved crop productivity.

Our data showed that participants started to involve outsiders, i.e. not family members, more in their discussions about farm management. At the same time, they addressed officials more to solve problems in the neighbourhood. Farmers also started discussions with extension workers in relation to farm management more easily than before and they became more specific in their ambitions to learn about agriculture. All in all, such observations pointed to a clear change in attitude.

7.3.4.3 Process - Were changes a result of involvement in participatory experimentation?

With respect to involving officials in discussions about farm management, involving officials in solving neighbourhood problems and the responses given in relation to learning ambitions, differences between participants and control group were significant. In retrospect over 80% of the participants indicated clear positive changes with respect to the incidence of poverty and the productivity of the lands. The contrast with the control group with respect to these issues was found to be significant, suggesting that these changes were related to involvement in the participatory experimentation.

In interviews farmers indicated that sharing knowledge through discussions was an important benefit for them. The workshops supported such discussions by providing the topic and the data required. They also frequently indicated that they had learned through their involvement in experimentation (sharing ideas, observing and taking the best, seeing in practice, experiencing opportunities). Responses of participants with respect to questions on involvement, benefits and actual changed practices appeared consistent. Whether these changes were a result of learning remains to be seen. However, they might give indications of the impact of four years of collaborative involvement.

7.3.4.4 Process - What kept farmers involved?

Answering the question why participants continued to be involved in the group experimentation over a period of more than four years could not be answered clearly. Outcomes of our evaluation of a set of factors, that we assumed being important for continuation of group experimentation did not indicate pronounced single factors, except the factor *"benefits"*, that explained farmers' motivation and participation in a consistent way. Also authors like Islam et al. (2011), Mapfumo et al. (2013) and Ndekha et al. (2003) found that benefits appeared to be very important in motivating participants to continue with their experimentation. However, at the same time these benefits were outcomes of the process of experimentation. Consequently, *"benefits"* were not only a source of motivation but also an intrinsic part of the process. This suggests that more complexity is involved in the process than is provided by a simple cause-effect rationality. In addition to that, participatory approaches are assumed to be context-dependent (Martin and Sherington, 1997). Implementing participatory experimentation, therefore, requires the use of approaches sufficiently flexible to address both complexity and context-dependency.

What other specific sources of motivation are required to initiate and maintain the process cannot be indicated based on our data. Factors probably compensated each other to some extent, as was also suggested by Islam et al. (2011) in his study of farmer-led extension groups. Lacking leadership might, for example, be compensated by coherence, lack of embeddedness in networks probably might be compensated partly by group-diversity. Had several groups dropped out, we might have had more lessons on this point.

Involvement in participatory experimentation requires transaction costs (Home and Rump, 2015; Morris and Bellon, 2004). For the farmers that participated in our research opportunity costs (Butler and Adomowski, 2015; Neef and Neubert, 2011) due to participation in the workshops were most important; these costs were covered by providing a *per diem*. In addition, yield losses on the host fields were compensated; other costs were limited since the farmers involved managed their fields in the usual way.

Hoffmann et al. (2007) commented that meaningful collaborative research requires specific attention for the following aspects: (1) user orientation, (2) farmer involvement, (3) farmer inclusion in experimentation, (4) diffusion of farmer knowledge and (5) fairness with respect to opportunity costs. Comparing these five points, in retrospect, with our set-up of participatory experimentation, we regarded them as fairly respected.

In his overview of collaborative research in Kenya, Ramisch (2012) indicated that collaborative efforts in the end became somewhat "institutional" and that associated social aspects ensured community embedding. This coincides to some extent with our observations that the group contributed a *"something"* that we tried to capture as *"group quality"*. This *"something"* probably is not only a factor supporting involvement but also an output of participatory experimentation. Although such denominations might appear as a *"black box"*, our expectation is that the compound factor *"group quality"* is essential in gaining and keeping momentum. Consequently, *"group quality"*, which is actually an aggregate of different and variable aspects, is important in participatory experimentation. In addition, facilitation (of participation) also involves affective factors, like for example enthusiasm and attention, that likely played a major role in motivating participants (Patrick et al., 2000; Wentzel et al., 2010).

7.3.4.5 Outcomes - What were direct results?

Outcomes and impact often appear two sides of the same coin and differentiating between them was in some cases challenging. In our analysis we considered outcomes being direct results from involvement, whereas impact related to change observed, for example, in relation to functional or human-social aspects. Having impact therefore meant that outcomes had materialized into actual change.

In relation to human-social aspects farmers indicated that they acquired technical knowledge and skills. In addition, they highlighted that sharing ideas took place, not only between farmers and researchers but also between farmers themselves; the experimentation became a platform for discussion and exchange of ideas. Sharing ideas in this way is considered an important output of sound participatory experimentation (Akpo et al., 2015; Mayoux and Chambers, 2005; Ramisch, 2012). With respect to functional aspects farmers made progress in their experimentation and achieved average yield-responses of about 76% in their best treatments as compared to control experiments and some 44% higher than responses achieved on farmer fields (Kraaijvanger and Veldkamp, 2017). All groups continued their involvement and the groups included more and more treatments that bore their own signature.

7.3.4.6 Did learning occur ?

Learning implies that change has taken place, for example, in knowledge, in skills, in attitude, in behaviour or in worldview (Jarvis et al., 2003). Some specific changes seemed related to involvement in participatory experimentation. Farmers mentioned, for example, improved technical skills, deeper knowledge on the application of fertilizers and sharing ideas.

When taking a meta-perspective on the outcomes of interviews and observations some general comments can be made. If learning was indeed responsible for the changes in farmers' practices and attitudes, such learning then might be referred to in terms of both single and double-loop learning (Argyris and Schon, 1974). The experimentation itself, resulting in confidence and competence in using practices that might lead to higher crop productivity, could be labelled as single-loop learning. Considering the series of experiments, we observed that groups explored new types of experiments. They shifted from a more traditional to a more advanced orientation in the selection of their treatments in which now combinations of traditional and modern practices were included. Also others involved in participatory experimentation observed comparable shifts (Fujisaka et al., 1994b; Ramisch et al., 2006; Vandeplas, 2010). Such a fundamental change in farmer behaviour could be considered as a (modest) form of double-loop learning (Armitage et al., 2008).

Recently, also Cornish et al. (2015) observed in line with this that farmers not only acquired functional knowledge but at the same time started managing their own learning. Considering the outcomes of their responses in relation to perceived benefits of involvement we observed that farmers not only appreciated the technical benefits but also valued the process in which they had been involved, they had learned how to learn together. Such a reflection on learning then even might point to third-order learning in the sense of Bateson (1972).

7.3.4.7 The researcher side: process, outcomes and impact

In participatory experimentation learning should take place for all participants involved, in our case farmers and researchers. This learning, depending on objective and context, however, does not need to be the same (Faure et al., 2014; Kaufman et al., 2014). We, for example, did not involve directly in farmers' (functional) learning at field level but instead took a meta-perspective at a more general (human-social) level. In retrospect, we applied a specific tool (participatory experimentation) to learn about it in terms of process, outcomes and impact. At the same time, our involvement in participatory experimentation with 16 farmer groups resulted in better understanding complexity at field level: what worked in one site often had no effect in another site and the other way around.

Considering the process from a functional point of view our involvement was restricted primarily to facilitation of the experiments and workshops. To obtain, however, at meta-level insights and understanding, we observed and monitored farmers' involvement and achievements. With respect to human-social aspects of the process we supported commitment, ownership and confidence of the groups.

With respect to (functional) outcomes we found that differences between high-input treatments and farmers' fields were often limited and that, at the same time, the combined treatments the farmers proposed, were quite effective. Therefore, we sometimes appeared to be *"bad farmers"* (see also Ramisch (2014)). An important human-social outcome for us was the observation that, unexpectedly, all 16 groups continued their experimentation.

Impact with respect to human-social aspects was achieved at a meta-level in the form of an increased understanding and insight in the process of participatory experimentation. Observations made throughout our involvement, for example, with respect to continuation of the groups and the performance farmers achieved, resulted in an increased confidence and belief in the potential of farmer experimentation. In addition, our involvement resulted in being more socially accepted and becoming less outsider and more insider. Identifying functional impact was difficult; arriving at more general recommendations with respect to farm management, which is often an overlying objective of researchers involved in participatory experimentation (Arévalo and Ljung, 2006; Martin and Sherington, 1997; Sturdy et al., 2008), might have been one, however, this was not achieved.

Insights and understanding in relation to participatory processes directly resulted from our involvement: this points to single-loop learning. At the same time, double-loop learning occurred for the researchers. We observed, for example, that the farmers were quite effective in their experiments and on their own fields; also the contrast between controls and farmer fields was striking.

At the same time, we were surprised by their commitment, the fact that they continued their involvement and the very effective treatments they often proposed. All this changed our view; not only our initial presumptions with respect to the low performance of farmers' practices were eroded, also our confidence in delegating responsibility for experimentation with the farmers was increased (see also Kraaijvanger and Witteveen (2018)).

7.3.4.8 Addressing functional and human-social aspects in participatory experimentation

In our participatory experimentation change was demonstrated with respect to both functional as well as human-social aspects. Still, in evaluating participatory processes the primary focus often is on the more tangible functional outputs, leaving the equally important human-social aspects unaddressed. As a consequence attention for human-social aspects of the process will be limited (Martin and Sherington, 1997).

For example, in processes that are more controlled by scientists a shift in focus to functional aspects is likely for reasons of accountability with respect to project outcomes (Baskerville and Wood-Harper, 1996; Martin and Sherington, 1997). Achieving change/impact with respect to human-social aspects, however, will require purposive involvement of farmers in all phases (Ashby and Pretty, 2006; Campbell and Vainio-Mattila, 2003; Hellin et al., 2008; Nederlof et al., 2004), which also will result in a different role for the researchers involved.

Long-term evolutionary processes are required to achieve (sustainable) change with respect to human-social and functional aspects (Douthwaite et al., 2003; Hellin et al., 2008; Misiko, 2009). Still, as was reported also by Ramisch (2014), we initially felt some frustration about not achieving quick visible functional changes since we were not in full control of the process (and context). In the course of our involvement, however, it became clear that even with complete control such changes were not likely and that on a long-term, changes with respect to human-social aspects were equally rewarding and most likely more sustainable.

7.3.4.9 Implications for the use of participatory experimentation in rural development processes

Participatory experimentation processes are in the spotlight of rural development processes. At the same time, outcomes of these participatory processes are heavily debated, for example with respect to effectiveness and type of impact (Bentley, 1994; Farrington, 1997; Farrington and Nelson, 1997; Kapoor, 2002). The interaction we outlined between process, outcomes and impact indicated that to achieve functional and human-social impact requires purposive adjustment of processes in order to secure involvement of farmers. In line with this we recommend the level of control executed by the farmers to be as high as possible. Only in this way self-fulfilling prophecies of not having impact will not materialize.

In participatory processes context is the *"alpha and omega"*. However, this context should not only relate to functional aspects connected with direct outcomes, but also to human-social aspects associated with the process. The finding that identification of a clear set of single success-factors in our case was not possible indeed pointed to context-dependency of the process. In designing participatory processes we therefore recommend, in agreement with, for example, (Butler and Adomowski, 2015; Duraiappah et al., 2005; Kaufman et al., 2014; Misiko, 2009; Raymond et al., 2010; Rocheleau, 1994), to adjust the process in an adaptive way in accordance with the context in which groups operate.

A major concern in this is process facilitation and especially the availability of trained facilitators (Bentley, 1994; Butler and Adomowski, 2015; Mayoux and Chambers, 2005). In addition, user-defined constraints clearly should be the point of departure in participatory experimentation; only then participants will perceive related benefits later on (Galabuzi et al., 2014; Sumberg, 2005; Van De Fliert, 2003).

Participatory experimentation in an agricultural context serves different (but connected) objectives: developing and adapting technology, learning, (final) adoption of technology and empowerment (Choudhary and Surf, 2013; Duraiappah et al., 2005; Hassenforder et al., 2015; Hellin et al., 2008). At the same time, benefits of participatory experimentation in relation to costs are often questionable (Martin and Sherington, 1997).

Development of technology and its adoption are important for public organizations, learning and empowerment are important concerns for NGOs (Farrington, 1998). In implementing and outscaling participatory experimentation it makes sense to combine efforts and expertise of both public organizations and NGOs (Hellin et al., 2008). For, example, the (costly) development of effective approaches in both functional and human-social terms, could be the mandate of NGOs, whereas public organizations in a more cost-effective way might cover further outscaling. Such interaction and co-operation then will serve as a first step in establishing networks and innovation platforms comprising different levels in the context of Agricultural Innovation Systems (AIS) and Agricultural Innovation and Knowledge Systems (AKIS) (Biggs, 2007; Röling et al., 2014; Wood et al., 2014), addressing in this way also non-technical components of innovation.

7.4 Conclusion

Participatory experimentation with 16 farmer groups in Tigray (Ethiopia) resulted in our case in a continuation of their involvement in this experimentation during the whole four-year period. At the same time, major changes relating to agricultural practice, experimentation and attitude were observed.

When comparing responses of participants to those of an independent control group, we observed that some of the attitudinal changes were significant. Also reported changes in livelihood aspects were significant and matched with involvement in participatory experimentation. In addition, congruency between responses relating to agricultural practice, learning and perceived benefits suggested that changes reported might be related to involvement in participatory experimentation.

Participants indicated that their motivation came mostly from benefits in the form of obtaining technical knowledge and probably also from sharing knowledge. Generally speaking, participants considered their participation worthwhile and highlighted learning as being important.

In evaluating a set of factors that might be influencing involvement we only found technical benefits in the form of reasonable yield responses being overall important. All other factors were highly variable among the groups and appeared to be trade-offs rather than knock-out factors. In designing processes of participatory experimentation it is, therefore, important to take such non-uniform sets of impact factors into careful consideration. Given the diversity of groups and the context in which they operate, blue-print approaches are not likely to sufficiently address associated variability.

Including process characteristics, outcomes and impact of the participatory experimentation in our analytical framework highlighted that change took place and that process, outcomes and impact were connected. At the same time we found functional and human-social aspects of agricultural (livelihood) systems affected in a positive way by participatory involvement. As a consequence, well-managed processes are required to achieve impact of participatory approaches in rural development. In other words participatory experimentation is not a *panacea* but requires instead careful adjustment and fine-tuning with local context and stakeholders to achieve the impact required for transformation of agricultural systems.

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8 Synthesis

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8.1 The research project: an overview

8.1.1 Context and research questions

In 2008 I embarked on a research project with the ambition to explore the effectiveness of participatory experimentation in the context of small-scale low-input farming in northern Ethiopia. My primary field of attention related to outcomes and process of participatory experimentation, the farmers involved and its implementation at grassroots level. For that purpose I engaged in, and monitored group-based participatory experimentation with farmers in Tigray from November 2008 until November 2014.

Participatory experimentation was framed in terms of Action Research, which can be considered a form of experiential learning (Checkland and Holwell, 1998). In Action Research-settings farmers and researchers engage in co-learning (Almekinders et al., 2009; Faure et al., 2014), but have, at the same time, often different roles, responsibilities and objectives (Baskerville and Wood-Harper, 1996; Ramisch, 2012; Sumberg et al., 2003).

Right from the start I had, in line with e.g., Ashby and Pretty (2006), Biggs (2007), Farrington (1997), Hellin et al. (2008) and Wood et al. (2014), a double focus: both achievements in terms of agricultural productivity and empowerment were considered relevant in relation to effectiveness. Therefore, I differentiated between effectiveness in terms of functional aspects and human-social aspects. Functional aspects included, for example, defining improved practices or changes in crop management (Farrington, 1998; Farrington and Nelson, 1997; Hellin et al., 2008); human-social aspects related to achieving human and social benefits for the farmers and communities involved, for example, in terms of learning and empowerment (Duraiappah et al., 2005; Musvoto et al., 2015; Smajgl and Ward, 2015). In addition, I was interested if the involvement of farmers in participatory experimentation, in line with its promises, indeed would support contextual relevancy of technologies and practices developed.

The primary research questions of this project were identified as assessing effectiveness of participatory experimentation in terms of: (1) relevancy of outcomes for the farmers and the context in which they operate; (2) change resulting from involvement in participatory experimentation with respect to functional aspects; (3) change resulting from involvement in participatory experimentation with respect to human-social aspects.

Questions relating to meta-level understanding of the process and its outcomes were, in a more exploratory way, defined as: (4) what are characteristics of the process of participatory experimentation and what factors do influence this process; (5) what are the relationships between experimental outcomes and different agronomic factors.

Effectiveness was considered in relation to technologies and practices matching better with local context and generating functional and human-social outputs more than in comparison with a control group of farmers. Effectiveness in terms of investments in time and resources (Martin and Sherington, 1997) in my project was not considered *per se*, the same holds true for my personal gains as being partner in joint experimentation.

Assessing effectiveness (research questions no 1-3) implied that change due to the involvement in participatory experimentation needed to be considered. These changes were assumed to be diverse and not only related to changes in crop productivity and farm management practices but also to changes in behaviour, in attitude and in world view of the participants (Smajgl and Ward, 2015).

In relation to characterizing and understanding the process of participatory experimentation I was specifically interested in how process and context had influenced actual participatory experimentation, for example, in how the groups operated, or with respect to development of trust and commitment (research question no 4). At the same time, I wanted to know if the outcomes of the field experiments allowed generalization in an agronomic sense (Faure et al., 2014; Martin and Sherington, 1997; Ramisch, 2012), for example, in the form of recommended practices (research question no 5).

Consequently, my analytical lens focused on monitoring functional outputs, human-social outputs, process and context, taking roles of both farmers and researchers into account. I engaged in farmers' experimentation, but at the same time took a meta-position, not only to address my research questions, but also to obtain understanding of participatory experimentation.

As a next step in this synthesis, I explored if change had contributed to livelihood development, for example, by reducing poverty, by increasing food security, or by increasing social and human capital of the participants (Barrera-Mosquera et al., 2010; Duraiappah et al., 2005; Leeuwis, 2000). Finally, based on insights resulting from my involvement, I wanted to reflect and to comment on the potential of participatory experimentation in supporting rural development.

8.1.3 Structure of synthesis

Each of the chapters in this thesis addressed specific stages of the research process, starting in chapter 2 with the selection of suitable methods for the identification of crop productivity constraints and ending in chapter 7 with changes that resulted from the experimentation and farmers' involvement in it. In this synthesis, I reflect at a higher level of abstraction on findings and understanding resulting from my involvement in participatory experimentation.

First, an integral discussion of my research project in terms of my research questions on effectiveness, understanding of the process and agronomic causality is presented. Then, I reflected on the process of participatory experimentation using the research cycle and my points of departure (see Chapter 1) as a guidance. In a separate section also the potential for scaling of participatory experimentation processes in relation to livelihood development is extensively commented, specifically in the context of Tigray.

8.2 Assessing effectiveness: putting pieces together

8.2.1 Outcomes of the chapters

In chapter 2-7 of my thesis different aspects relating to participatory experimentation were covered: what methods can be used to identify constraints, what problem was prioritized; what experimental outcomes were obtained; how did these outcomes relate to context; what strategies did farmers employ; what did participants learn; how did farmers and their livelihood change. In this section the main findings of each chapter are related to my research questions.

In assuring contextual relevancy it was essential to include participatory methods, in which farmers are in control and find their opinion represented. At the same time, involving farmers in constraint identification might result in achieving important functional and human-social benefits in terms of quality of interventions, ownership and commitment (Chapter 2).

Using focus group discussion, farmers identified local constraints and opportunities with their livelihood system as a primary reference. Identifying in these discussions not only constraints but also opportunities underlined that farmers were seriously committed to address their problems. Direct involvement of farmer-stakeholders in the process of constraint identification resulted in functional and human-social benefits. For example, in the form of addressing contextual complexity and supporting empowerment (Chapter 3).

Regression analysis of experimental outcomes indicated that local environmental context and farm management explained a huge proportion of the variability observed. Consequently, participatory on-farm experimentation resulted in functional outcomes that were relevant, useful and valid within the local farming system context (Chapter 4).

Farmers prepared research designs in which experimental outcomes were blended with context and tradition-based ideas (Chapter 5). Participants achieved, in comparison to current practice, increased yield levels, pointing to benefits with respect to functional aspects (Chapter 6). Farmer groups gradually changed, in the course of their involvement, the type of experiments included to more complex and innovative combinations of practices, indicating a simultaneous change of human-social aspects in the form of attitude and knowledge.

Outcomes of experiments aiming at improving crop yield need interpretation to make them operational within farmers' livelihood-systems. Outcomes of a mental exercise using different perspectives highlighted that, given the different interpretations possible, an assessment of functional aspects of change will be dependent on perspective and, consequently, be subjective (Chapter 6).

Based on my own and farmer-reported observations I found that personal change of participating farmers took place with respect to their attitude and worldview and that they apparently had become more empowered. At the same time, farmers reported that their farm management practices had changed and that they had obtained more knowledge and skills. Consequently, change took place with respect to both human-social and functional aspects (Chapter 7).

8.2.2 My research questions revisited

By making use of direct experimental outcomes and longitudinal changes observed and based on long-term monitoring of process, participants and a control group, I was able to (partly) answer my research questions on effectiveness, understanding of the process and agronomic causality:

(1) Was contextual relevancy achieved?

I found that participatory experimentation was, in line with one of its claims (Anderson et al., 2016; Chambers and Jiggins, 1987a; Van De Fliert, 2003), effective in including context. Main constraints identified by the farmers in the FGDs were diverse and reflected a location specific context. Involvement of farmers in crucial research phases (i.e. problem identification, design and evaluation) was intentional and farmers used this opportunity to include various aspects of context (farming system, livelihood requirements, tradition, local needs), resulting in relevant context-specific outcomes (Chapter 3; Chapter 5).

(2) Did participatory experimentation contribute to change with respect to functional aspects?

Within the context of the experimentation conducted and based on my own and farmer-reported observations I conclude that functional change was achieved in terms of increased crop yield and development and performance of farmer-defined practices (Chapter 5; Chapter 7). Participatory experimentation therefore has a clear potential to provide functional benefits for the farmers involved. Specific (functional) outputs like satisfactory responses of farmer-defined treatments, combining traditional and recommended practices, addressing farming system requirements and reported increase of crop yield and reduction of poverty, support this conclusion.

(3) Did participatory experimentation contribute to change with respect to human-social aspects?

Based on my analysis of research strategies of (farmer) participants and my interviews with participants and control group farmers I observed that: participants used outcomes of previous experiments to design new experiments (Chapter 5); participants started including elements of systematic experimentation in their designs (Chapter 5); participants changed their attitude towards discussing farm management (Chapter 7); participants clearly indicated the desire to acquire knowledge on specific agricultural practices (Chapter 7); participants addressed officials more easily (Chapter 7); participants became more and more confident (Chapter 7). I therefore conclude that farmers' involvement in participatory experimentation had contributed to human-social change in terms of knowledge, attitude and empowerment.

(4) What are characteristics of the process of participatory experimentation and what factors do influence this process?

Connecting process, outcomes, and impact of participatory experimentation I conclude that: process and outcomes were context dependent (Chapter 7;(Martin and Sherington, 1997)); process, outcomes and impact were (logically) related (Chapter 7); farmers did not pursue achieving functional outcomes in a systematic linear way, but instead focused on achieving contextual relevancy by seeking combinations with existing practices (Chapter 5; Totin et al. (2013)). In relation to factors influencing the participatory process, I found that real participation of farmers in the evaluation and design phases of the research was essential in making groups more confident (Chapter 7). Furthermore, all other factors that I had assumed being supportive for farmer involvement were variable among the groups, except for the factor benefits (Chapter 7). In addition to the above conclusions, I reflect in section 8.3 more specifically on the participatory process as it developed.

(5) In what way were experimental outcomes and agronomic factors related ?

Regression analysis indicated that outcome variability (of on-farm experiments) could be explained by a set of different agronomic variables (Chapter 4). Furthermore, nutrient balances showed that increasing crop yield by applying fertilizer appeared to promote depletion (Chapter 6). Still, demonstrating causality in highly complex (on-farm) settings was, in general, difficult. Direct relationships of crop yield with soil nutrient content were, for example, not explicit (Chapter 4).

8.3 Reflection on process and points of departure

8.3.1 Introduction

One of the most interesting points in my research project was the observation that all groups kept being involved. This observation, however, did not result in the identification of essential (success) factors except for perceiving benefits (functional) and becoming confident (human-social). As indicated before, process, outcomes and impact were found to be related and especially process and outcomes appeared connected through feedback loops created by the repeated cycles of experimentation and the FGDs. In this reflection I intend to identify consistencies in process and points of departure. For that purpose both the process observed and the points of departure are discussed separately.

8.3.2 Reflection on the process of participatory experimentation

Like in most Action Research-settings I followed a series of (connected) research cycles, aiming at progressive learning. Farmers involved in these cycles with the objective to learn about and to develop technologies and practices aiming at increased crop yield. To obtain deeper understanding of the process and factors involved in participatory experimentation I focused on the research cycles shaping it. These research cycles, and the different phases constituted in them, can be characterized by the actual process taking place and the different inputs and outputs involved.

In participatory settings distribution of responsibilities is an important aspect; in this case responsibilities were shared among farmers and the researchers[1] and changed deliberately over the five-year duration of my project (Fig. 8.1). Farmers had, from the start onwards, full responsibility for analysis of experimental outcomes and field management. Researchers had a main responsibility for experimental management (like measuring inputs, delineating experimental fields, sampling and harvesting).

In the first year, in addition to the treatments that farmers proposed, researchers included replications, controls and promising treatments. In the later years, researchers more and more withdraw from including treatments in the

[1] Researchers here include: author (main researcher), supervisors and field assistants.

experimental layout; simultaneously transferring this responsibility to the farmers. Throughout, however, controls were included. In the last two years of their involvement farmers also progressively obtained more responsibilities for experimental management (harvesting and determining crop yield).

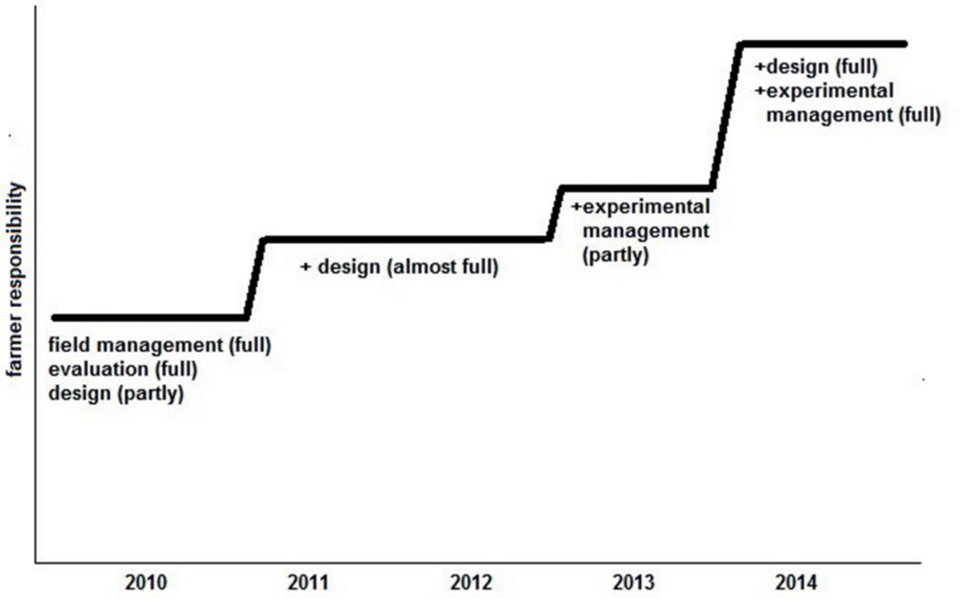


Fig. 8.1: Progressive increase of farmer responsibility over the years of their involvement (2010-2015), ranging from shared responsibility (with researchers) to having full responsibility.

Problem identification

Farmers initially identified a variety of constraints to which low crop yields could be attributed. Farming and livelihood systems were obviously extremely complex and single constraining factors, therefore, were not identified. Instead, mind maps with different problems and opportunities were constructed (Chapter 3). Farmers had full responsibility for the preparation of these mind maps. This high level of involvement supported confidence and resulted in research topics that were familiar. In addition, it provided a sense of ownership (Hagmann et al., 2003) for the farmers that were involved. A true (problem) identification phase, however, was not really present in the later cycles and analysis of outcomes was mainly connected to the design phase. Still, in the course of their involvement, farmers, being challenged by us, repeatedly indicated that they wanted to continue their experimentation in relation to crop productivity and soil fertility.

Farmers' responsibility for problem identification was essential as otherwise pre-analytical choices made by researchers would control major parts of the research (see also Ayenor et al. (2004) and Hounkonnou et al. (2006)). By giving control to the farmers in the problem identification process, the impact of pre-analytical choices, for example, due to discipline and experience of the researcher, was excluded as much as possible (Chapter 2). Minimizing (subjective) pre-analytical choices in the problem identification phase is important as these not only will affect the problems identified but later on also affect interpretation and, consequently, might result in different pathways to development (Chapter 6).

Design of experiments

Farmers used experimental outcomes as a main input for their designs, which gave their experiments a systematic character. These experiences were blended with other insights and with tradition, curiosity and farmers' contextual reference framework (Chapter 5). Farmers were eager to experiment and even included many untypical treatments and did not necessarily follow mainstream scientific ideas. Farmers, in short, employed a complex and original strategy to arrive at a research design, not restricting themselves to pre-defined options.

Farmers, initially, were somewhat cautious to use their mandate to design the experiments, but later on took this responsibility very serious and with flair. Farmers obviously had a permanent need to adapt to changing conditions (Boillat and Berkes, 2013) and continuous experimentation was for them a way to stay up-to-date in addressing context and, as a consequence, an important survival strategy (Leitgeb et al., 2014; Richards, 1986). Research, consequently, can be seen as part of farmers' daily routine and different authors indicated before that farmers are by default experimenters, although not in a formal scientific way (Okali et al., 1994; Rocheleau, 1994).

Experimentation

The on-farm experiments were diverse and in field visits farmers appreciated *"seeing different options in practice"*. Farmers rapidly familiarized with the formal and systematic lay-out of the experiments (including, for example, delineated plots and controls), which differed considerably from the way farmers normally experiment (Hoffmann et al., 2007; Martin and Sherington, 1997; Rocheleau, 1994; Sumberg et al., 2003). Still farmers did not copy one-to-one: they used, for example, instead of the 3 x 3 m plots (later on) often 1 x 1 m plots, which likely related to scarcity of land and ease of delineation.

Evaluation

To allow all (even illiterate) farmers to be involved in the evaluation of the experiments, required the use of an easily understandable format (Akpo et al., 2015; Defoer et al., 1998; Mayoux and Chambers, 2005; Neef and Neubert, 2011; Pretty, 1995; Wood et al., 2014). Farmers tended to focus on high produce, but in their designs also considered their actual farming system and demonstrated this, for example, by prioritizing treatments with a higher straw produce or including traditional approaches, using in fact a contextual lens. Farmers became very confident in their evaluation. Visual observations made, for example, during field visits were, however, not so much considered as the time span between these observations and the evaluation in the workshops was over six months. Farmers' evaluation due to this tended to be more based on quantitative yield of grains and straw than on more subjective observations such as grain size and the presence of weeds.

Résumé: sharing responsibilities is essential

At different stages in participatory experimentation processes choices are made that have impact throughout. Farmers involving in participatory experimentation will make choices on the basis of the complexity of their farming and livelihood systems. Being submerged in their specific context, farmers will include this context in a rather intuitive way. Researchers, in general, will try to address context by multi-factorial experiments, or will exclude context for the sake of experimental control or reproducibility. Therefore, in settings of participatory experimentation, decisions made by farmers often will diverge from those made by researchers. Respecting such differences requires a transfer of responsibilities to the farmers and consequently maximum involvement of farmers in all research phases is essential. This has also been claimed by Anderson et al. (2016), de Souza et al. (2012, Musvoto et al. (2015), Nederlof et al. (2004) and Raymond et al. (2010).

Taking these responsibilities resulted in participants becoming very confident about conducting research. Once they had seen how the field experiments were organized, this rapidly became internalised. In the later workshops farmers only needed a small hint to go on by themselves, they knew what to do, were dedicated and responsibilities were clear to them.

Farmers appeared proud of their involvement, as was reported by Ramisch (2012), and in their houses I saw, for example, the maps they used during the workshops as a wall decoration (Fig. 8.2). All this supported my view that in involving farmers in participatory experimentation, facilitators should not be too afraid to have the groups swimming freely, as long as they have a small lifeline.

Fig. 8.2: A farmer's house decorated with a chart used in the workshop.

8.3.2 Reflection on points of departure

My participatory experimentation approach was not fixed beforehand and for reasons of efficiency I concentrated on documenting the process rather than controlling it (see also Arévalo and Ljung (2006)). Instead of a well-defined research protocol I used an iterative approach on the basis of a set of nine specific points of departure (see Chapter 1). Based on this framework the farmer groups were facilitated in a similar, but not identical, way. These points of departure were assumed to support involvement and to optimize interaction in participatory experimentation. In retrospect, I reflected below on the role of these points of departure in my research project.

Long-term involvement

A long-term involvement was envisaged and in line with recommendations provided by, for example, Guijt (2008), I involved farmers for five years in participatory experimentation and monitored in this period technical as well as social achievements. Such a time span not only was relevant for the purpose of monitoring and evaluation in terms of reliability but also allowed farmers to gain confidence and to develop skills for an effective participation. Participatory experimentation was new for them and farmers clearly needed time to accommodate to this new role. Change of farmers became manifest in the second half of their involvement: learning takes time.

Farmers involve as a group

Group work almost is the default option in participatory experimentation (Pretty, 1995; Tumbo et al., 2011; Yami, 2016). In my case workshops were the main group event, second came field visits (organized). All other meetings between farmers (and myself) were more occasional and, for example, took place during sowing and harvesting of the experimental fields. Participating farmers co-operated in groups and group members were selected based on information provided by BoARD-staff; they could be classified as innovators and early adopters (Leeuwis, 2004).

The composition of the neighbourhood-based farmer groups was quite constant and most of its members stayed involved throughout. Participants, in general, shared a genuine interest in novel technologies (Chapter 7). Groups were heterogeneous (with respect to age, gender and wealth) and consisted out of about 5-6 persons (Chioncel et al., 2003; Poteete and Ostrom, 2004). This number was effective in securing involvement of all group members as well as to provide sufficient momentum. Group heterogeneity helped to represent different stakeholders within a community, like in my case female-headed households and young farmers.

Domination by individuals or groups is an important risk for group work and is often associated with differences in power, wealth and gender (Butler and Adomowski, 2015; Hagmann, 2000; Mudege et al., 2015; Neef and Neubert, 2011; Poteete and Ostrom, 2004). In my case domination appeared not a major issue and groups, in general, were very respectful. Literacy was a more serious concern as most groups had only one or two literate persons, but this did not result in domination. Participants, in general, organized themselves very well and working with groups matched very well with the ”natural” way of co-operation of Tigray farmers, like, for example, in *Aider* groups (traditional community support groups; see also Gebregziabher et al. (2016), Gebregziaher et al. (2013), Hailu (2009), Yami et al. (2011)) and in collective action in the context of Food-For-Work.

The group itself was an essential, but oblique, factor in explaining continuation (Chapter 7). Social aspects of co-operating in groups appeared the main motivating factor and social achievements like, for example, trust, confidence and having responsibility, were important in supporting the process (see also Badstue et al. (2006), Cundill and Rodela (2012), Home and Rump (2015) and Ramisch (2012). The group served as the fuel for the process and, therefore, needed to be fostered as such. At the same time, the groups were the forum where learning and interaction took place and in my case represented a format that apparently suited the farmers.

Delegating responsibilities

Participatory experimentation processes follow research cycles with specific phases (i.e., problem identification, design, data collection and evaluation). In each of these phases choices are made that are decisive for the further course of the research. In my research project farmers had as much as possible responsibility for each of these phases. This meant that the research team deliberately concentrated on facilitation and, therefore, did not provide any direct cognitive inputs to farmers’ experimentation and problem solving.

Sharing responsibilities was extremely relevant for on-going participation (see also Ayenor et al. (2007)) and essential to achieve learning and sharing of ideas (see also Faure et al. (2014)). Different authors, like for example, de Souza et al. (2012), Musvoto et al. (2015), Raymond et al. (2010) and Van De Fliert (2003), emphasized the necessity to give farmers a role in research dealing with their problems. Providing a serious mandate is, even in the context of participatory experimentation, in many cases neglected and farmers' role often restricted to selecting varieties (Misiko, 2013; Trouche et al., 2012; Waldman et al., 2014) or providing fields for on-farm demonstrations (Misiko et al., 2008). In retrospect, I would, based on my personal experiences and depending on context, delegate responsibilities to participants even sooner.

Facilitation

In participatory experimentation facilitation is essential and (local) facilitators need to be trained to support the groups involved and the process (Bentley, 1994; Butler and Adomowski, 2015; Mayoux and Chambers, 2005). Facilitators need to be sensitive towards the backgrounds of participatory work and should not only appreciate functional achievements but also the aspect of empowerment. Roles of facilitators in my research project included supporting the experiments and data-collection, supporting group processes, supporting the experimental processes, suggesting novel technology for the purpose of momentum (Hoffmann et al., 2007; Sumberg et al., 2003) and assuring a just distribution of responsibilities. In the trade-off between scientific rigor and (farmer) involvement, the latter was prioritized.

Control over the experimentation process was almost fully delegated to the farmer groups, while researchers focused on overall facilitation of the process. Handing over control over the research process to farmer groups was an essential component of my facilitation and I noticed that without such explicit emphasis, top-down approaches appeared programmed. Another important aspect of facilitation was the use of visual methods and numbers and other less demanding formats to achieve understanding of outcomes by the farmers (Akpo et al., 2014; Defoer et al., 1998; Mayoux and Chambers, 2005; Neef and Neubert, 2011). I consider, in line with Mapfumo et al. (2013), the feedback of quantitative data to participants an essential process input. The use of numbers (all farmers trade on the weekly markets) and visual presentations of data (farmers are used to small containers as an unit of measurement) were effective and helped the farmers to structure their discussion and evaluation.

Reducing dependency of farmers on researcher input and facilitation

In the course of my involvement farmers progressively obtained more responsibilities for all aspects of experimentation. They were, however, insecure about taking this responsibility and questioned us frequently, especially about the how-to-do-it: how to weed; how to take measurements; how to apply fertilizer and compost. Coming up with a design was considered easy; drawing the actual lay-out of the experiment on a paper sheet a burden. Small steps still meant progress and farmers appreciated support in taking them. While reducing facilitation participants should not get lost; a core expertise in facilitation relates to knowing when to step back and to transfer responsibility.

Local context

One of the main objectives of participatory experimentation is arriving at contextually relevant outcomes (Okali et al., 1994) and in my case 16 different on-farm sites resulted in variable outcomes. Next to treatment, contextual (and farmer) factors very well explained variability observed (Chapter 4). At the same time, participatory experimentation was, despite its "unscientific" appearance, effective in achieving reliable and rigorous outcomes. Obtaining scientific rigour in on-farm experiments therefore is possible, for example, by including replications, controls and contextual data (Mayoux and Chambers, 2005; Rocheleau, 1994).

Taking an *"on-farm"* perspective is essential in defining optimal practices; in the context of low external input agriculture *"best bets"* not necessarily need to be best everywhere (Rigolot et al., 2017). An important concern I had at the start of the series of experimentation cycles was the impact of climatic variability since rainfall in Tigray is considered erratic and highly variable (Nyssen et al., 2005). In the course of my involvement meteorological conditions were reasonably stable and no real (devastating) drought occurred. More incidental events affecting experimentation locally were flooding and hail in Hagere Selam and Hawzen; anticipating for such events is, however, in general very difficult.

Incentives

Incentives were, in line with our points of departure, reduced to those based on learning and interaction. Opportunity costs resulting from participation (Butler and Adomowski, 2015; Hoffmann et al., 2007; Neef and Neubert, 2011) were, however, respected and covered by us (following BoARD’s regulations in this). Making benefits and progress visible for the farmers was essential in securing involvement of farmers (Islam et al., 2011; Mapfumo et al., 2013; Ndekha et al., 2003). Field visits and providing quantitative information on yield were important tools in achieving this. As farmers were in charge of main parts of experimental design and problem identification, current needs were likely to be addressed sufficiently (Galabuzi et al., 2014; Okali et al., 1994; Sumberg, 2005; Van De Fliert, 2003).

Control group

A major effort I undertook was including a control group of farmers (“non-participants”). This control group and all participating farmers were interviewed at the start and at the end of the research period. Outcomes of both surveys led to essential and meaningful outcomes and allowed a comparison in relation to change. Although farmers were living in each other’s neighbourhood, interaction between both groups appeared limited. Involvement required a substantial time investment from the side of the farmers and occasional observations or discussion were, in general, not sufficient to replace direct involvement.

Systematic monitoring

Researchers monitored the experiment with respect to inputs, harvested yield and crop development. From the start of and throughout the process systematic monitoring of participating farmers through interviews and observations took place. This monitoring was important to keep in touch with the farmers and to observe changes with respect to knowledge and attitude. Monitoring at the same time provided inputs to fine tune the actual research project in an iterative way. Examples included learning about the appreciation of farmers for straw produced and the usefulness of legumes as crop sown before cereals.

Résumé: bleu-prints are unwanted

Many scholars indicated before that blue-print approaches in social learning contexts in most cases won’t work (Biggs, 2007; Blackmore, 2007; Butler and Adomowski, 2015; Douthwaite et al., 2003; Duraiappah et al., 2005; Kaufman et al., 2014; Okali et al., 1994; Poteete and Ostrom, 2004; Raymond et al., 2010; Reed et al., 2009; Rocheleau, 1994; Totin et al., 2015) and also my analysis of group functioning and involvement indicated that all factors considered (except for benefits) were variable among the groups (Chapter 7).

This variability in group antecedents and characteristics is important and needs to be respected. Participatory experimentation is a context dependent process (Martin and Sherington, 1997) and requires care in designing and implementing it. Exploiting the whole potential of Action Research in terms of functional and human-social aspects requires a deliberate focus on involvement, especially if also empowerment is opted for.

From my observations central themes for successful participatory experimentation revolve around having responsibilities, effective facilitation, group work and confidence. On the basis of my experiences in facilitating participatory experimentation and without pointing to any blue-print the following points appeared, in retrospect, essential in supporting farmer involvement: (1) delegating responsibilities; (2) heterogeneous groups; (3) group size of about five participants; (4) respecting opportunity costs; (5) suggesting novel technology; (6) considering actual needs; (7) understandable formats; (8) visible benefits; (9) flexible and iterative approaches.

8.4 Impact, livelihood development and scaling

8.4.1 Impact on farmers and their livelihoods

Involvement of farmers in participatory experimentation resulted in change with respect to functional and human-social aspects (Chapter 7). These observations raised the question if change observed also correlated with impact in a wider, more generic, sense; i.e., change of farmers and their livelihoods.

Change of farmers relates to (personal) change, for example, in knowledge, attitude and skills. In the context of my research project farmers became confident in experimentation and obtained knowledge and skills of novel technologies (Romina, 2014; Van Der Wal et al., 2014). Farmers were before, for example, insecure about methods of applying fertilizers and the amounts required; applying mineral fertilizers meant a considerable investment for them and was perceived as risky. Farmers also learnt about systematic experimentation and became with respect to attitude more outspoken.

Following van Mierlo et al. (2010), I observed that different aspects of farmers' identity changed in a positive way: knowledge, confidence, social trust and responsibility. At the same time, using the conceptual framework of Fazey (2010), I conclude that epistemological beliefs of the farmers had changed towards using other sources of knowledge (i.e. from relying on external sources to knowledge generated through interaction). Such perceptual changes indicated that double-loop learning (Argyris and Schon, 1974) and transformation outside traditional frames of reference (Duveskog et al., 2011) took place. Changes observed, overall, suggest some level of empowerment of the farmers involved (Chapter 7).

Change in the way farmers dealt with their local context, definitely took place: they became more in control with respect to acquiring knowledge; they spent time to work in groups; groups stayed together and shared ideas and responsibilities. Farmers appreciated their involvement in the research and became more empowered (Chapter 7). In their experiments they came up with effective combinations that linked traditional practices with Integrated Soil Fertility Management (Vanlauwe et al., 2010) and the concept of low-input high-efficiency agriculture (Altieri et al., 2012). Less poverty and increased crop production meant for them becoming less vulnerable, for example, with respect to food security.

Livelihoods can be seen as a set of different interacting capitals (Bebbington, 1999) and assessing overall impact on livelihoods, as a consequence, is not easy. In my case only limited indication of how livelihoods changed can be provided: farmers reported that crop yield had increased (natural capital) and poverty had declined (financial capital); at the same time some change with respect to co-operation took place and existing structures of interaction appeared to be strengthened in the process (social capital).

8.4.2 Livelihood development and the role of participatory experimentation

In Tigray, high pressure on available resources resulted in degraded farming systems and lacking resilience (Nyssen et al., 2004). Due to the impact of climate change these degraded farming systems have become even more fragile and vulnerable and at present farming systems with considerable adaptive capacity are urgently required (Rurinda, 2014). Having worked for five years with farmers on the prospect of bringing about a positive transition towards higher crop yield and more food security, automatically brings up the question if outcomes of my involvement indeed offered feasible options for sustainable transition.

On the con-side a number of less encouraging characteristics can be identified: agricultural fields in Tigray are small, people are many, the environment is risky, farmers are risk-averse and local economies underdeveloped. Especially farmers' perception of risk (Gebrehiwot and van der Veen, 2015; George, 2014) and food security (personal observation) appear important determinants in the context of livelihood development.

Still, on the pro-side, my involvement demonstrated that crop productivity clearly has possibilities to improve and in some cases improved already. By preparing nutrient balances I found that traditional systems were quite effective in balancing inputs and outputs of nutrients at field level in a sustainable way (Chapter 6); sustainability which is also witnessed by the existence of comparable farming systems in Tigray for over 2500 years (McCann, 1995).

Far more than anticipated, farming systems are complex. Using manure; feeding straw and weeds to livestock (Chapter 3); labour shortage; using legumes; agroforestry; fallowing; farmers frequently ploughing the land (Nyssen et al., 2011); terracing: all seems to fit together. Such complexity results in resilient systems but also will complicate implementation of novel technologies. Practices like using mineral fertilizers likely fit within existing farming systems, a practice like conservation agriculture (Giller et al., 2009; Vanlauwe et al., 2014), however, requires considerable adaptation of actual farming systems (Tittonell et al., 2012). Recommending single technologies consequently in most cases will not suffice in achieving farming system transition.

Low-input high-efficiency agriculture and long-term sustainability appear key concepts matching with current agricultural complexity in Tigray and allowing at the same time smooth transition of current farming systems. Such prospects definitely benefit from good lands with deep soils which are terraced and supplied with organic and mineral fertilizers to close nutrient cycles. Some outcomes developed by the farmer groups already fit with the concept of low-input high-efficiency agriculture and actual crop yield on such lands with good management and fertilizer input was promising (over 5000 kg/ha) and came close to model predictions (GYGA, 2016). Next to improving crop productivity, farmers also have other opportunities to improve their livelihood: seasonal labour; small scale household irrigation (Hailu, 2009); forestry (Reij & Smaling, 2008); apiculture; livestock; cash crops like fruits and vegetables (Woldewahid et al., 2011).

Site variability and complexity of farming systems in the project area were high and required context specific recommendations. At the same time, correcting sub-optimal situations through adaptive management is difficult because of the short growing period. Precision agriculture, as is practised in Europe and North America, might be a solution but in sub Saharan Africa in most cases the high resolution soil and weather data required (van Groenigen et al., 2000) are not always available.

In relation to implementing novel technology, the assumption is often forwarded that farmers select from a *"basket of options"*, without considering the need for context specific modifications. Such modifications require farmer involvement and the *"best bet"* appears the one that involves farmers as early as possible in adaptation processes (Hoffmann et al., 2007). Especially in the case of low-input high-efficiency agriculture, fine tuning with a complex context and taking small iterative steps to keep pace with the farmers are essential.

Transitions are not only about technology but also require social components to be addressed (Beers et al., 2014). Participatory experimentation contributes to this as farmers involving in participatory experimentation may learn not only about crop management but also learn with respect to values, beliefs and attitude (Smajgl and Ward, 2015) or, as was reported by Cornish et al. (2015), may become more independent and start managing their own learning.

Change realized by participatory processes, as by default, will be only in small incremental steps: farmers will not move much outside the space within the boundaries of knowledge, biophysical context, risk and market. Because of this limited solution-space change will not be very dramatic. Sustainability, however, might be considerable as involvement of farmers likely secures concerns of people, planet and profit (Chapter 6; Elkington (2002)).

Participatory experimentation, therefore, not only constitutes a feasible option to improve farmer livelihoods by combining development of site specific recommendations with capacity building, but also has a clear potential to act as a change agent (rather than providing the "solution") and trigger transitions towards more sustainable systems.

8.4.3 Scaling participatory experimentation

In Tigray different actors are active in promoting agricultural development. The main actor in rural development processes in Tigray is the Bureau of Agriculture and Rural Development (BoARD). Through its network of Farmer Training Centres and development agents, BoARD actively promotes novel technologies, mostly through Transfer of Technology approaches (Hailu, 2009)). This is done in the form of all-inclusive packages or as single technologies. Packages were assumed to have more impact on farmers' livelihoods (Gebregziabher et al., 2016; Rigolot et al., 2017; Tittonell and Giller, 2013) but some experiences indicated that adoption of multiple innovations in packages was difficult for farmers (Spielman et al., 2010) due to financial risks and the need for change of existing farming systems.

In Tigray, many other (non-governmental) organizations dealt at different scales with identification of innovative practices and their dissemination. Examples of such initiatives were, for example, the May Zegzeg-project in Dogua Tembien (Lanckriet et al., 2014) and the CASCAPE project (CASCAPE, 2014). Main tools used in both projects were participatory identification of suitable practices and establishing demonstration plots, exemplifying that participation in Tigray in many cases remained limited to the *"consultative"* level (Biggs, 1989).

On the basis of my experience with participatory experimentation for over five years, I consider responsibility of farmers in all stages of participatory processes a major concern. The same holds true for embedding farmer responsibility in existing extension structures to *"bottom-up"* the approaches used more. Adoption of novel practices, often a main point of reference for rural development programs, appears less primary from a meta-perspective: the true objective should be farmer involvement. Participation is an *"end"* and not simply a *"means"* to secure functional achievements (Ajakaiye and de Janvry, 2010; Campbell and Vainio-Mattila, 2003; Leeuwis, 2000; Parfitt, 2004). This brings us to a somewhat Zen-like statement that *"not the goal but the way to it"* is what enlightens and most likely secures adoption.

Innovations at grassroots level, for example generated through participatory experimentation, are not always sufficient to bring about sustainable change. In general, niche-type innovations can be very effective within their specific context, but to accommodate with and to bring about change of higher-level formal and informal institutions is often difficult (Schut et al., 2015b). Lack of change at higher scale levels affects sustainability of innovations at lower levels.

The concept of Agricultural Innovation Systems (AIS) takes a wider perspective and tries to combine efforts of extension, education, knowledge institutes and commercial partners to achieve innovation by effectively facilitating the implementation of relevant novel technology. Building institutions, networks and platforms in this way is assumed to result in change, not only in the form of improved practices but also at an institutional level (Biggs, 2007; Klerkx et al., 2010; Röling et al., 2014; Schut et al., 2015a; Spielman et al., 2008; Suchiradipta and Ray, 2015; Wood et al., 2014; Yami, 2016).

At present extension and knowledge institutes (universities and research) often co-operate in a more horizontal way but integration of efforts could be optimized by including and supporting also up- and downward vertical processes (Cooper and Wheeler, 2015) and involving, as Suchiradipta and Ray (2015) remarked for India, more commercial partners.

Finally, the impact of innovations definitely does not stop at the farm gate, but also affects stakeholders at other scale levels. Developing innovative technologies, therefore, needs to be accompanied by scaling strategies that result into practices addressing concerns of stakeholders at multiple scale levels (Wigboldus et al., 2016).

Although networks and institutions, in general, are considered important in the context of innovation systems and innovation capacity (Röling et al., 2014; Spielman et al., 2008; Yami, 2016) it was not clear to me to what extent the soft system in our case had to expand further (i.e. beyond grassroots level) and how networks and institutions were decisive for the participatory process. Still, involving local institutions (Cooper and Wheeler, 2015) while respecting the grassroots level (Suchiradipta and Ray, 2015) and having a clear focus on user constraints (Sumberg, 2005), appeared an appropriate next step.

The role of extension workers in this is obvious and their involvement in AIS mandatory since they are closest to the grassroots level. In Tigray, for example, also supply of agricultural requirements like improved seeds and fertilizers is arranged through extension bureaus (Gebremednin et al., 2006; Spielman et al., 2010). In contrast to most NGOs, BoARD has a clear structure, a considerable number of staff and the capacity to reach almost every village and therefore appears well equipped to implement participatory experimentation.

The scale level at which groups operate appears at best *cushet* level[2]. This means that in each tabia several groups will be active. Optimum group size should be about five participants to ensure clear responsibilities. Groups should be cohesive and stratified with respect to gender and age (Probst, 2002). Groups could be facilitated by appointing specific development agents at *tabia* level[3] responsible for facilitation of experimentation. The *tabia* level also appears adequate for the dissemination of experiences through organized field visits for local farmers.

To arrive at effective participation, approaches should be group specific and based on open processes in which feedback is essential and responsibilities are delegated to the farmers in all phases of development (i.e. planning and implementation). Only in this way it is assured that farmers' perspective is reflected in the outcomes achieved. This recommendation fits with the present transformation of extension services in Ethiopia towards becoming less top-down (Gebregziaher et al., 2013).

Facilitation is essential in participatory experimentation and this will, given the specific requirements of this type of intervention work, require specific training of facilitators (Butler and Adomowski, 2015; Mayoux and Chambers, 2005). The main task in facilitation will be to initiate the process and to keep momentum (Dalal-Clayton and Dent, 2001).

Delegating responsibilities increasingly to farmers (Marquardt et al., 2009) definitely will reduce their dependency on external support and facilitation, which is an important and costly factor for out-scaling. Empowerment of farmers through participatory experimentation in this way directly will pay off. Facilitated

[2] Cushet = community level
[3] Tabia = (sub)district level

workshops appear a highly effective platform for interaction and crucial in supporting participatory experimentation processes.

8.5 Conclusion: Five years - one lesson

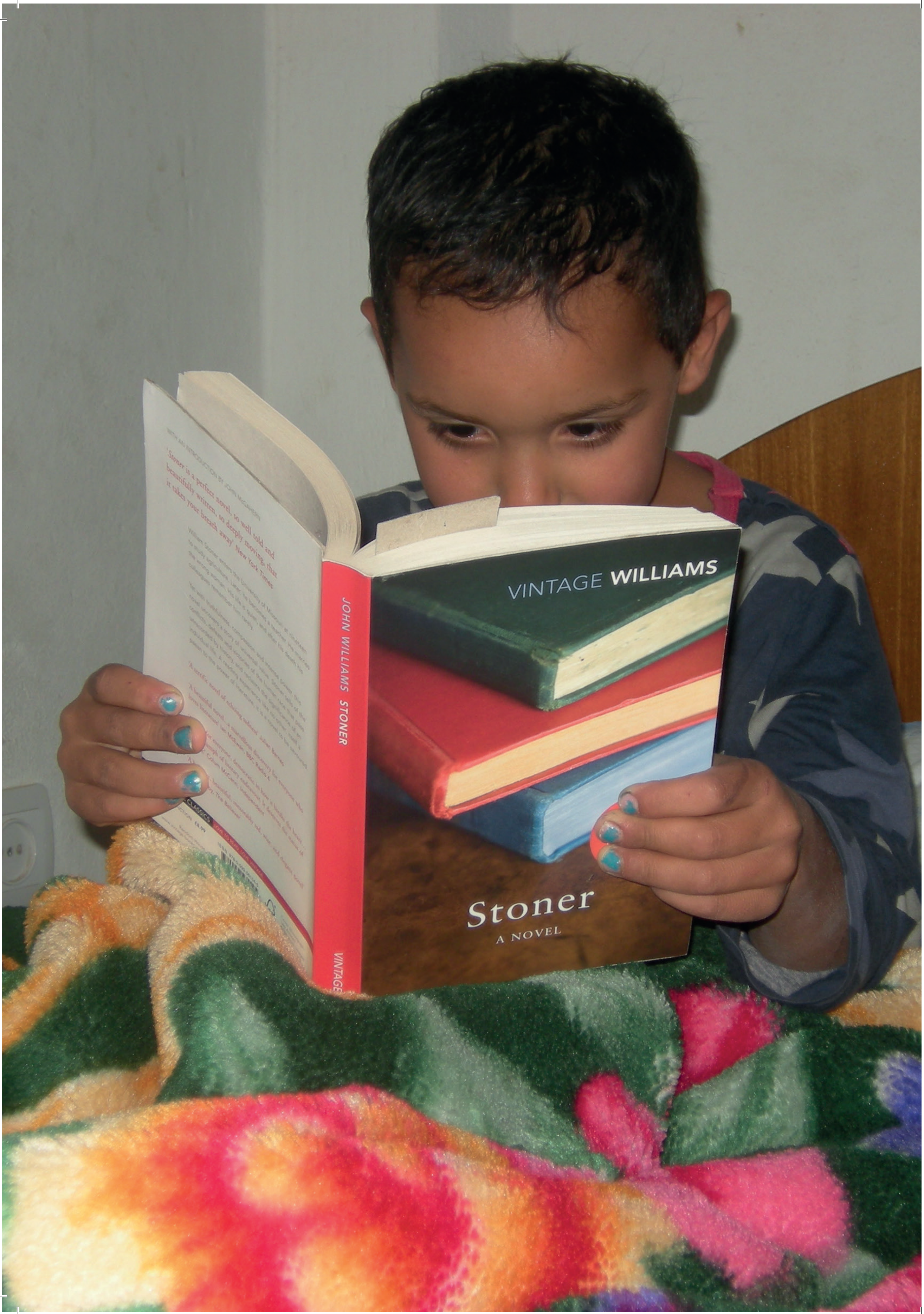
Involvement of farmers and myself in participatory experimentation was envisaged to achieve both (functional) experiential learning and different forms of empowerment of farmers. Experimentation in this served as a vehicle ("*means*") to secure "*ends*" in terms of achieving relevant functional outcomes and hosting the participatory process that resulted in important human-social outcomes.

For the farmers involved outcomes achieved were substantial and relevant: yield increase, knowledge and confidence being most important. Next to this, participatory experimentation resulted in better mutual understanding of perspectives held by farmers and scientists, reducing in this way the gap between their views.

At the same time, farmers often make choices different from those scientists would opt for; including their ideas and perspective in research concerning their livelihood is essential in achieving relevant functional and human-social outcomes. Participatory experimentation therefore cannot be ignored as alternative to more traditional ways to increase production capacity in the context of low input agricultural systems.

Human-social outcomes and contextual relevancy were extremely influenced by an explicit choice for maximum involvement of farmers in the research; confidence clearly grew with respect to analysing outcomes, preparing designs and managing the experiments. Farmers' learning was not only related to knowing the best way, but also towards confidence in finding the best way.

Farmers, therefore, definitely need to be given the lead and their perspective needs to be respected in order to fully exploit the virtues of participatory experimentation, even if this might be uncomfortable for other stakeholders involved. In this way participatory experimentation becomes a feasible option to initiate transitions towards more sustainable livelihood systems.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References

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 on Agriculture 40, 213-220.

Abegaz, A., 2005. Farm management in mixed crop-livestock systems in the Northern Highlands of Ethiopia. Tropical Resource Management Papers 70, Plant Production Systems. Wageningen University, Wageningen, The Netherlands.

Abegaz, A., van Keulen, H., Oosting, S.J., 2007. Feed resources, livestock production and soil carbon dynamics in Teghane, Northern Highlands of Ethiopia. Agricultural Systems 94, 391-404.

Affholder, F., Scopel, E., Neto, J.M., Capillon, A., 2003. Diagnosis of the productivity gap using a crop model. Methodology and case study of small-scale maize production in central Brazil. Agronomie 23, 305-325.

African-Development-Bank, 2016. Feed Africa: Strategy for Agricultural Transformation in Africa 2016-2025. Available under: www.afdb.org/. Accessed: 21-12-2016.

Ajakaiye, O., de Janvry, A., 2010. Agricultural sector performance and a green revolution in Africa: An overview. Journal of African Economies 19, ii3-ii6.

Ajayi, O.C., 2007. User acceptability of sustainable soil fertility technologies: Lessons from farmers' knowledge, attitude and practice in Southern Africa. Journal of Sustainable Agriculture 30, 21-40.

Akpo, E., Crane, T.A., Vissoh, P.V., Tossou, R.C., 2015. Co-production of Knowledge in Multi-stakeholder Processes: Analyzing Joint Experimentation as Social Learning. Journal of Agricultural Education and Extension 21, 369-388.

Almekinders, C., Beukema, L., Tromp, C., 2009. Research in Action. Theories and practices for innovation and social change. Wageningen Academic Publishers, Wageningen, The Netherlands.

Almekinders, C., Hardon, J., 2006. Bringing Farmers Back into Breeding. Experiences with Participatory Plant Breeding and challenges for institutionalisation. Agromisa, Wageningen.

Altieri, M.A., Funes-Monzote, F.R., Petersen, P., 2012. Agroecologically efficient agricultural systems for smallholder farmers: Contributions to food sovereignty. Agronomy for Sustainable Development 32, 1-13.

Anderson, W., Johansen, C., Siddique, K.H.M., 2016. Addressing the yield gap: a review. Agronomy and Sustainable Development 36:18.

Andersson, E., Gabrielsson, S., 2012. 'Because of poverty, we had to come together': Collective action for improved food security in rural Kenya and Uganda. International Journal of Agricultural Sustainability 10, 245-262.

Araya, A., Keesstra, S.D., Stroosnijder, L., 2010. A new agro-climatic classification for crop suitability zoning in northern semi-arid Ethiopia. Agric. For. Meterol. 150, 1057-1064.

Araya, T., Cornelis, W.M., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., Raes, D., Sayre, K.D., Haile, M., Deckers, J., 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use Manage 27, 404-414.

Arévalo, K., Ljung, M., 2006. Action Research on Land Management in the Western Amazon, Peru – A Research Process, Its Outcomes and the Researcher’s Role. Systemic Practice and Action Research 19, 309-324.

Argyris, C., Schon, D.A., 1974. Theory in practice: Increasing professional effectiveness. Jossey-Bass, Hoboken NJ.

Armitage, D., Marschke, M., Plummer, R., 2008. Adaptive co-management and the paradox of learning. Global Environmental Change 18, 86-98.

Asfaw, A., Almekinders, C.J.M., Blair, M.W., Struik, P.C., 2012. Participatory approach in common bean (Phaseolus vulgaris L.) breeding for drought tolerance for southern Ethiopia. Plant Breeding 131, 125-134.

Ashby, J., Pretty, J., 2006. Commentary: Participatory research for sustainable agricultural research and development. International Journal of Agricultural Sustainability 4, 97-98.

Astatke, A., Jabbar, M., Tanner, D.G., 2003. Participatory conservation tillage research: an experience with minimum tillage on a Ethiopian highland Vertisol. Agriculture, Ecosystems & Environment 95, 401-415.

Ayenor, G.K., Röling, N.G., Padi, B., Van Huis, A., Obeng-Ofori, D., Atengdem, P.B., 2004. Converging farmers' and scientists' perspectives on researchable constraints on organic cocoa production in Ghana: Results of a diagnostic study. NJAS - Wageningen Journal of Life Sciences 52, 261-284.

Ayenor, G.K., Van Huis, A., Obeng-Ofori, D., Padi, B., Röling, N.G., 2007. Facilitating the use of alternative capsid control methods towards sustainable production of organic cocoa in Ghana. International Journal of Tropical Insect Science 27, 85-94.

Badstue, L.B., Bellon, M.R., Berthaud, J., Juárez, X., Rosas, I.M., Solano, A.M., Ramírez, A., 2006. Examining the role of collective action in an informal seed system: A case study from the Central Valleys of Oaxaca, Mexico. Human Ecology 34, 249-273.

Barrera-Mosquera, V., de los Rios-Carmenado, I., Cruz-Collaguazo, E., Coronel-Becerra, J., 2010. Analysis of available capitals in agricultural systems in rural communities: The case of Saraguro, Ecuador. Spanish Journal of Agricultural Research 8, 1191-1207.

Bartholomew, W.V., Clark, F.E., 1965. Soil nitrogen. American Society of Agronomy, Madison.

Baskerville, R.L., Wood-Harper, A.T., 1996. A critical perspective on action research as a method for information systems research. Journal of Information Technology 11, 235-246.

Bateson, G., 1972. Steps to an ecology of mind: Collected essays in anthropology, psychiatry, evolution, and epistemology. University of Chicago Press, Chicago.

Bebbington, A., 1999. Capitals and capabilities: a framework for analyzing peasant viability, rural livelihoods and poverty. World Development 27, 2021-2044.

Bedada, W., Karltun, E., Lemenih, M., Tolera, M., 2014. Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. Agriculture, Ecosystems & Environment 195, 193-201.

Beers, P.J., Hermans, F., Veldkamp, T., Hinssen, J., 2014. Social learning inside and outside transition projects: Playing free jazz for a heavy metal audience. NJAS - Wageningen Journal of Life Sciences 69, 5-13.

Bekele, W., 2006. Analysis of farmers' preferences for development intervention programs: A case study of subsistence farmers from East Ethiopian Highlands. African Development Review 18, 183-204.

Bellon, M.R., Reeves, J., 2002. Quantitative Analysis of Data from Participatory Methods in Plant Breeding. CIMMYT, Mexico.

Bentley, J.W., 1994. Facts, Fantasies, and Failures of Farmer Participatory Research. Agriculture and Human Values Spring-Summer, 140-150.

Berhanu, K., Poulton, C., 2014. The Political Economy of Agricultural Extension Policy in Ethiopia: Economic Growth and Political Control. Development Policy Review 32, 199-216.

Beyene, A., Gibbon, D., Haile, M., 2006. Heterogeneity in land resources and diversity in farming practices in Tigray, Ethiopia. Agricultural Systems 88, 61-74.

Biggs, S., 1989. Resource-poor farmer participation in research: A synthesis of experiences from nine national agricultural research systems. OFCOR Comparative Study. 3ISNAR, The Hague, Netherlands.

Biggs, S., 2007. Building on the positive: An actor innovation systems approach to finding and promoting pro poor natural resources institutional and technical innovations. 6, 144-164.

Biggs, S., Matsaert, H., 1999. An actor-oriented approach for strengthening research and development capabilities in natural resource systems. Public Administration and Development 19, 231-262.

Biggs, S., Smith, G., 1998. Beyond Methodologies: Coalition-building for Participatory Technology Development. World Development 26, 239-248.

Blackmore, C., 2007. What kinds of knowledge, knowing and learning are required for addressing resource dilemmas ? A theoretical review. Environmental Science & Policy 10, 512-525.

Blackstock, K.L., Kelly, G.J., Horsey, B.L., 2007. Developing and applying a framework to evaluate participatory research for sustainability. Ecological Economics 60, 726-742.

Boardman, S., 1999. The agricultural foundation of the aksumite empire, Ethiopia, in: Van der Veen, M. (Ed.), The Exploitation of Plant Resources in Ancient Africa. Kluwer Academic/Plenum Publishers, New York, pp. 137-147.

Boillat, S., Berkes, F., 2013. Perception and interpretation of climate change among quechua farmers of bolivia: Indigenous knowledge as a resource for adaptive capacity. Ecology and Society 18.

Boyd, B.L., Dooley, K.E., Felton, S., 2006. Measuring learning in the affective domain using reflective writing about a virtual international agriculture experience. Journal of Agricultural Education 47, 24.

Braimoh, A.K., Vlek, P.L.G., Stein, A., 2004. Land Evaluation for Maize Based on Fuzzy Set and Interpolation. Environmental management 33, 226-238.

Braun, A.R., Thiele, G., Fernández, M., 2000. Farmer field schools and local agricultural research committees: complementary platforms for integrated decision-making in sustainable agriculture. Overseas Development Institute London.

Brooks, S., 2014. Enabling adaptation? Lessons from the new 'Green Revolution' in Malawi and Kenya. Climatic Change 122, 15-26.

Butler, C., Adomowski, J., 2015. Empowering marginalized communities in water resources management: addressing inequitable practices in Participatory Model Building. Journal of Environmental Management 153, 153-162.

Byers, P.Y., Wilcox, J.R., 1991. Focus Groups: A Qualitative Opportunity for Researchers. The Journal of Business Administration 28, 63-78.

Campbell, B., Hagmann, J., Sayer, J., Stroud, A., Thomas, R., Wollenberg, E., 2006. What kind of research and development is needed for natural resource management? Water International 31, 343-360.

Campbell, L.M., Vainio-Mattila, A., 2003. Participatory Development and Community-Based Conservation: Opportunities Missed for Leassons Learned? Human Ecology 31, 417-437.

CASCAPE, 2014. The Cascape project: demand driven innovation development for agricultural growth in Ethiopia. Available under: http://www.cascape.info/phocadownload/2014/introduction_cascape_project.pdf . Assessed: 19-08-2014.

CASCAPE, 2014a. Cascape Thematic Brief #3. Validated best practices and innovations. Available online under: http://www.cascape.info/phocadownload/2014/validated%20best%20practices%20and%20innovations.pdf. Accessed: 15-08-2014.

Chambers, R., Conway, G.R., 1992. Sustainable rural livelihoods: practical concepts for the 21st century. IDS Discussion Paper 296.

Chambers, R., Jiggins, J., 1987a. Agricultural research for resource-poor farmers Part I: Transfer-of-technology and farming systems research. Agricultural Administration and Extension 27, 35-52.

Chambers, R., Jiggins, J., 1987b. Agricultural research for resource-poor farmers part II: A parsimonious paradigm. Agricultural Administration and Extension 27, 109-128.

Checkland, P., Holwell, S., 1998. Action Research: Its Nature and Validity. Systemic Practice and Action Research 11, 9-21.

Chioncel, N.E., Van der Veen, R.G.W., Wildemeersch, D., Jarvis, P., 2003. The validity and reliability of focus groups as a research method in adult education. International Journal of Lifelong Learning 22, 495-517.

Choudhary, A.K., Surf, V.K., 2013. On-Farm Participatory Technology Development Effects on Resource Conservation Technologies in Rainfed Upland Paddy in Himsachal Pradesh, India. Communications in Soil Science and Plant Analysis 44, 2605-2617.

Ciampalini, R., Billi, P., Ferrari, G., Borselli, L., Follain, S., 2012. Soil erosion induced by land use changes as determined by plough marks and field evidence in the Aksum area (Ethiopia). Agriculture, Ecosystems and Environment 146, 197-208.

Coll-Black, S., Gilligan, D.O., Hoddinott, J., Kumar, N., Wiseman, W., 2012. Targeting Food Security Interventions in Ethiopia: The Productive Safety Net. Food and Agriculture in Ethiopia: Progress and Policy Challenges 74, 280.

Cooper, S.J., Wheeler, T., 2015. Adaptive governance: Livelihood innovation for climate resilience in Uganda. Geoforum 65, 96-107.

Corbeels, M., Shiferaw, A., Haile, M., 2000. Farmers' knowledge of soil fertility and local management strategies in Tigray, Ethiopia. IIED-Drylands Programme.

Cornish, P.S., Choudhary, A., Kumar, A., Das, S., Kukumbakhar, K., Norish, S., Kumar, S., 2015. Improving crop production for food security and improved livelihoods on the East India Plateau II Crop options, alternative cropping systems and capacity building. Agricultural Systems 137, 180-190.

Cosyns, H., Van Damme, P., De Wulf, R., 2013. Who views what? Impact assessment through the eyes of farmers, development organization staff and researchers. International Journal of Sustainable Development and World Ecology 20, 287-301.

CSA, 2004. Agricultural Sample Survey 2003/2004. Volume I: Report on area and production of crops (private peasant holdings, Meher season). Statistical Bulletin 302, Addis Ababa.

CSA, 2014. Agricultural Sample Survey 2013-2014 (2006 E.C.) Volume I: Report on area and production of major crops (Statistical Bulletin 532), Addis Ababa.

CSA, 2016. Agricultural Sample Survey 2015/2016 (2008 E.C.) Volume I: Report on artea and production of major crops (Statistical Bulletin 584). Central Statistical Agency, Addis Ababa.

Cundill, G., Rodela, R., 2012. A review of assertions about the processes and outcomes of social learning in natural resource management. Journal of Environmental Management 113, 7-14.

Dalal-Clayton, B., Dent, D., 2001. Knowledge of the land: land resources information and its use in rural development. Oxford University Press.

De Groote, H., Rutto, E., Odhiambo, G., Kanampiu, F., Khan, Z., Coe, R., Vanlauwe, B., 2010. Participatory evaluation of integrated pest and soil fertility management options using ordered categorical data analysis. Agricultural Systems 103, 233-244.

de Souza, H.N., Cardoso, I.M., de Sá Mendonça, E., Carvalho, A.F., de Oliveira, G.B., Gjorup, D.F., Bonfim, V.R., 2012. Learning by doing: A participatory methodology for systematization of experiments with agroforestry systems, with an example of its application. Agroforestry Systems 85, 247-262.

Dea, D., Scoones, I., 2003. Networks of knowledge: How farmers and scientists understand soils and their fertility. A case study from Ethiopia. Oxford Development Studies 31, 461-478.

Defoer, T., 2000. Moving methodologies. Learning about integrated soil fertility management in sub-Saharan Africa, Plant Production Systems. Wageningen Agricultural University.

Defoer, T., De Groote, H., Hilhorst, T., Kanté, S., Budelman, A., 1998. Participatory action research and quantitative analysis for nutrient management in southern Mali: A fruitful marriage? Agriculture, Ecosystems and the Environment 71, 215-228.

Denning, G., Kabambe, P., Sanchez, P., Malik, A., Flor, R., Harawa, R., Nkhoma, P., Zamba, C., Banda, C., Magombo, C., Keating, M., Wangila, J., Sachs, J., 2009. Input subsidies to improve smallholder maize productivity in Malawi: Toward an African green revolution. PloS Biol. 7.

Dethier, J.J., Effenberger, A., 2012. Agriculture and development: A brief review of the literature. Econ. Syst. 36, 175-205.

Devereux, S., Sabates-Wheeler, R., Slater, R., Tefera, M., Brown, T., Teshome, A., 2008. Ethiopia's Productive safety Net Programmme (PNSP): 2008 Assssment Report.

Dienes, Z., Altmann, G., 2003. Measuring learning using an untrained control group: Comment on R. Reber and Perruchet. The Quarterly Journal of Experimental Psychology: Section A 56, 117-123.

Donovan, C., Wopereis, M., Guindo, D., Nebie, B., 1999. Soil fertility management in irrigated rice systems in the Sahel and Savanna regions of West Africa: Part II. Profitability and risk analysis. Field Crops Research 61, 147-162.

Doorenbos, J., Kassam, A.H., 1979. Yield response to water. FAO, Rome.

Douthwaite, B., Kuby, T., Van De Fliert, E., Schulz, S., 2003. Impact pathway evaluation: An approach for achieving and attributing impact in complex systems. Agricultural Systems 78, 243-265.

Drechsel, P., Gyiele, L., Kunze, D., Cofie, O., 2001. Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. Ecological Economics 38, 251-258.

Duraiappah, A.K., Roddy, P., Parry, J.-E., 2005. Have participatory approaches increased capabilities? International Institute for Sustainable Development, Winnipeg, Canada.

Duveskog, D., Friis-Hansen, E., Taylor, E.W., 2011. Farmer field schools in rural Kenya: A transformative learning experience. Journal of Development Studies 47, 1529-1544.

Ehui, S., Pender, J., 2005. Resource degradation, low agricultural productivity, and poverty in sub-Saharan Africa: Pathways out of the spiral. Agricultural Economics 32, 225-242.

Elkington, J., 2002. Cannibals with Forks: The Triple Bottom Line of the 21st Century. Oxford Press, Oxford.

Ellis, F., Biggs, S., 2001. Evolving themes in rural development 1950s-2000s. 19, 437-448.

FAO-ITPS, 2015. Status of World's Soil Resources (SWSR) - Main Report. Food and Agriculture Organization of the United Nations, Rome, Italy.

FAO-IUSS, 2006. World reference base for soil resources 2006: A framework for international classification, correlation and communication. FAO, Rome.

FAO, 1978. Report on the Agro-Ecological Zones Project. Methodology and Results for Africa

Food and Agricultural Organization, Rome.

FAO, 2014. FAO Statistical Databases. Available under http://www.faostat.fao.org. Assessed 13-08-2014.

FARA, 2014. Science Agenda for Agriculture in Africa‟ - Connecting Science” to transform agriculture in Africa. Available under: www.faraafrica.org/programs/frameworks/science-agenda/. Accessed: 21-12-2016.

Farrington, J., 1995. The changing public role in agricultural extension. Food Policy 20, 537-544.

Farrington, J., 1997. Farmers' participation in agricultural research and extension: Lessons from last decade. Biotechnology and Development Monitor, 12-15.

Farrington, J., 1998. Organisational roles in farmer participatory research and extension: lessons from the last decade. Natural Resource Perspectives 27.

Farrington, J., Nelson, J., 1997. Using logframes to monitor and review farmer participatory research. ODI Agricultural Research & Extension Network Network Paper No. 73.

Farrington, J., Thirtle, C., Henderson, S., 1997. Methodologies for monitoring and evaluating agricultural and natural resources research. Agricultural Systems 55, 273-300.

Faure, G., Gasselin, P., Triomphe, B., Temple, L., Hocdé, H., 2014. Innovating with rural stakeholders in the developing world: Action research in partnership. CTA LM Publishers / Presses Agronomiques de Gembloux, Wageningen, The Netherlands.

Fazey, I., 2010. Resilience and Higher Order Thinking. Ecology and Society 15.

Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A.C., Lambert, E., Hastings, E., Morris, S., Reed, M.S., 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Global Environmental Change 25, 204-220.

Flora, C.B., 2010. Food security in the context of energy and resource depletion: Sustainable agriculture in developing countries. Renewable Agriculture and Food Systems 25, 118-128.

Frankema, E., 2014. Africa and the green revolution a global historical perspective. NJAS - Wageningen Journal of Life Sciences 70, 17-24.

Frankl, A., Jacob, M., Haile, M., Poesen, J., Deckers, J., Nyssen, J., 2013. The effect of rainfall on spatio-temporal variability in cropping systems and duration of crop cover in the Northern Ethiopian Highlands. Soil Use and Management 29, 374-383.

Fujisaka, S., 1989. The need to build upon farmer practice and knowledge: reminders from selected upland conservation projects and policies. Agroforestry Systems 9, 141-153.

Fujisaka, S., Harrington, L., Hobbs, P., 1994a. Rice-wheat in South Asia: Systems and long-term priorities established through diagnostic research. Agricultural Systems 46, 169-187.

Fujisaka, S., Jayson, E., Dapusala, A., 1994b. Trees, grasses, and weeds: species choices in farmed-developed contour hedgerows. Agroforestry Systems 25, 13-22.

Galabuzi, C., Eilu, G., Mulugo, L., Kakudidi, E., Tabuti, J.R.S., Sibelet, N., 2014. Strategies for empowering the local people to participate in forest restoration. Agroforestry Systems 88, 719-734.

Gebregziabher, G., Rebelo, L.-M., Langan, S., 2016. Interdependence in rainwater management technologies and analysis of rainwater management adoption in the Blue Nile Basin. Environment, Development and Sustainability 18, 449-466.

Gebregziaher, K., Mathijs, E., Deckers, J., Gebrehiwot, K., Bauer, h., Maertens, M., 2013. The Economic Impact of a New Rural Extension Approach in Northern Ethiopia, Bioeconomics Working Paper Series. University of Leuven, Leuven, Belgium.

Gebrehiwot, T., Van der Veen, A., 2013. Assessing the evidence of climate variability in the northern part of Ethiopia. Journal of Development and Agricultural Economics 5, 104-119.

Gebrehiwot, T., van der Veen, A., 2015. Farmers Prone to Drought Risk: Why Some Farmers Undertake Farm-Level Risk-Reduction Measures While Others Not? Environmental Management 55, 588-602.

Gebrehiwot, T., van der Veen, A., Maathuis, B., 2011. Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. Int. J. Appl. Earth Obs. Geoinformation 13, 309-321.

Gebremednin, B., Hoekstra, D., Tegegne, A., 2006. Commercialization of Ethiopian agriculture: Extension service from input supplier to knowledge broker and facilitator, IPMS of Ethiopian Farmers Project Working Paper 1. ILRI, Nairobi, Kenya.

Gebreyohannes, T., De Smedt, F., Hagos, M., Gebresilassie, S., Amare, K., Kabeto, K., Hussein, A., Nyssen, J., Bauer, H., Moeyersons, J., 2010. Large-scale geological mapping of the Geba basin, northern Ethiopia. Tigray Livelihood Papers 9.

George, T., 2014. Why crop yields in developing countries have not kept pace with advances in agronomy. Global Food Security 3, 49-58.

Giller, K.E., Leeuwis, C., Andersson, J.A., Andriesse, W., Brouwer, A., Frost, P., Hebinck, P., Heitkönig, I., Van Ittersum, M.K., Koning, N., Ruben, R., Slingerland, M., Udo, H., Veldkamp, T., Van de Vijver, C., Van Wijk, M.T., Windmeijer, P.,

2008. Competing claims on natural resources: What role for science? Ecology and Society 13.

Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'Ungu, J., Mwale, M., Nwaga, D., Pacini, C., Vanlauwe, B., 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems 104, 191-203.

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114, 23-34.

Gorfu, A., Tanner, D.G., Geletol, L.Z.T., Yilmal, Z., Eliasi, E., Ethiopia, A.A., 1989. Derivation of economic fertilizer recommendations for bread wheat in the Ethiopian highlands: on-farm trials in the peasant sector, The Sixth Regional Wheat Workshop: For Eastern, Central and Southern Africa: Addis Ababa, Ethiopia, October 2-6, 1989. CIMMYT, p. 63.

Govindaraj, G., Kumari, J., Mishra, A., Bharti, V.S., 2010. Problem identification and prioritisation of research options: The PRA and AHP approach. Journal of Rural Development 29, 449-455.

Guijt, I.M., 2008. Seeking Surprise: Rethinking monitoring for collective learning in rural resource management, Agricultural Knowledge Systems. Wageningen University, Wageningen, p. 350.

GYGA, 2016. Global Yield Gap Atlas (GYGA). Available under: www.yieldgap.org. Accessed: 19-12-2016.

Habtegebrial, K., Ram Singh, B., Aune, J.B., 2007a. Wheat response to N2 fixed by faba bean (Vicia faba L.) as affected by sulfur fertilization and rhizobial inoculation in semi-arid Northern Ethiopia. Journal of Plant Nutrition and Soil Science 170, 412-418.

Habtegebrial, K., Singh, B.R., Haile, M., 2007b. Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of tef (Eragrostis tef (Zucc.) Trotter) and soil properties. Soil and Tillage Research 94, 55-63.

Hadgu, K.M., 2008. Temporal and spatial changes in land use patterns and biodiversity in relation to farm productivity at multiple scales in Tigray, Ethiopia, Biological Farming Systems. Wageningen University, Wageningen.

Hagmann, J., 2000. Learning together for change. Margraf Verlag, Weikersheim, Germany.

Hagmann, J., Chuma, E., Murwira, K., Connolly, M., 1998. Learning together through participatory extension: a guide to an approach developed in Zimbabwe. AGRITEX / GTZ / ITDG-Zimbabwe, Harare, p. 59.

Hagmann, J., Chuma, E., Murwira, K., Connolly, M., Ficarelli, P.P., 2003. Success Factors in Integrated Natural Resource Management R&D: Lessons from Practice, in: Campbell, B.M., Sayer, J.A. (Eds.), Integrated Natural Resource Management - Linking Productivity, the Environment and Development. CABI Publishing.

Haileslassie, A., Priess, J., Veldkamp, E., Teketay, D., Lesschen, J.P., 2005. Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances. Agriculture, Ecosystems and Environment 108, 1-16.

Haileslassie, A., Priess, J.A., Veldkamp, E., Lesschen, J.P., 2007. Nutrient flows and balances at the field and farm scale: Exploring effects of land-use strategies and access to resources. Agricultural Systems 94, 459-470.

Hailu, B., 2009. The impact of agricultural policies on smallholder innovation capacities, Communication and Innovation Studies. Wageningen University, Wageningen, p. 155.

Hall, A., Mytelka, L., Oyeyinka, B., 2006. Concepts and guidelines for diagnostic assessments of agricultural innovation capacity. UNU-MERIT, Maastricht Economic and Social Research and Training Centre on Innovation and Technology.

Haregeweyn, N., Poesen, J., Deckers, J., Nyssen, J., Haile, M., Govers, G., Verstraeten, G., Moeyersons, J., 2008. Sediment-bound nutrient export from micro-dam catchments in Northern Ethiopia. Land Degradation & Development 19, 136-152.

Hassenforder, E., Smajgl, A., Ward, J., 2015. Towards understanding participatory processes: Framework, application and results. Journal of Environmental Management 157, 84-95.

Havlin, J.L., Beaton, J.D., Tisdale, S.L., Nelson, W.L., 2005. Soil Fertility and Fertilizers. An Introduction to Nutrient Management. Pearson Education Inc., Upper Saddle River, NJ.

Hellin, J., Bellon, M.R., Badstue, L., Dixon, J., La Rovere, R., 2008. Increasing the impacts of participatory research. Experimental Agriculture 44, 81-95.

Henderson, B., Godde, C., Medina-Hidalgo, D., van Wijk, M., Silvestri, S., Douxchamps, S., Stephenson, E., Power, B., Rigolot, C., Cacho, O., Herrero, M., 2016. Closing system-wide yield gaps to increase food production and mitigate GHGs among mixed crop-livestock smallholders in Sub-Saharan Africa. Agricultural Systems 143, 106-113.

Hengsdijk, H., Meijerink, G.W., Mosugu, M.E., 2005. Modeling the effect of three soil and water conservation practices in Tigray, Ethiopia. Agriculture, Ecosystems and Environment 105, 29-40.

Hildebrand, P.E., Singh, B.K., Bellows, B.C., Campbell, E.P., Jama, B.A., 1993. Farming systems research for agroforestry extension. Agroforestry Systems 23, 219-237.

Hoffmann, V., Probst, K., Christinck, A., 2007. Farmers and researchers: How can collaborative advantages be created in participatory research and technology development? Agriculture and Human Values 24, 355-368.

Holden, S., Shiferaw, B., 2004. Land degradation, drought and food security in a less-favoured area in the Ethiopian highlands: a bio-economic model with market imperfections. Agricultural Economics 30, 31-49.

Holt-Giménez, E., 2008. Out of AGRA: The green revolution returns to Africa. Development 51, 464-471.

Home, R., Rump, N., 2015. Evaluation of a Multi-case Participatory Action Research Project: The Case of SOLINSA. Journal of Agricultural Education and Extension 21, 73-89.

Hounkonnou, D., Kossou, D.K., Kuyper, T.W., Leeuwis, C., Richards, P., Röling, N.G., Sakyi-Dawson, O., Van Huis, A., 2006. Conergence of Sciences: the management of agricultural research for small scale farmers in Benin and Ghana. NJAS - Wageningen Journal of Life Sciences 53, 343-367.

Howard, J.A., Kelly, V.A., Stepanek, J., Crawford, E.W., Demeke, M., Maredia, M.K., 1999. Green Revolution Technology Takes Root in Africa The Promise and Challenge of the Ministry of Agriculture/SG2000 Experiment with Improved Cereals Technology in Ethiopia. Michigan State University, Department of Agricultural, Food, and Resource Economics.

Islam, M.M., Gray, D., Reid, J., Kemp, P., 2011. Developing Sustainable Farmer-led Extension Groups: Lessons from a Bangladeshi Case Study. The Journal of Agricultural Education and Extension 17, 425-443.

Jama, B., Pizarro, G., 2008. Agriculture in Africa: Strategies to improve and sustain smallholder production systems, Annals of the New York Academy of Sciences, pp. 218-232.

Jarvis, P., Holford, J., Griffin, C., 2003. The theory & practice of learning, 2nd edition. RoutledgeFalmer, London.

Johnston, L.J., Renteria, A., Hannon, M.R., 2003. Improving validity of on-farm research. Journal of Swine Health and Production 11, 240-246.

Kaplowitz, M.D., Hoehn, J.P., 2001. Do focus groups and individual interviews reveal the same information for natural resource valuation? Ecological Economics 36, 237-247.

Kapoor, I., 2002. The devil's in the theory: a critical assessment of Robert Chambers' work on participatory development. Third World Quarterly 23, 101-117.

Kassie, M., Zikhali, P., Manjur, K., Edwards, S., 2009. Adoption of sustainable agriculture practices: Evidence from a semi-arid region of Ethiopia. Natural Resources Forum 33, 189-198.

Kaufman, S., Ozawa, C.P., Shmueli, D.F., 2014. Evaluating participatory decision processes: Which methods inform reflective practice? Evaluation and Program Planning 42, 11-20.

Kebede, E., Duncan, A., Klerkx, L., de Boer, I.J.M., Oosting, S.J., 2015. Understanding socio-economic and policy constraints to dairy development in Ethiopia: A coupled functional-structural innovation systems analysis. Agricultural Systems 141, 69-78.

Keeley, J., Scoones, I., 2000. Knowledge, power and politics: The environmental policy-making process in Ethiopia. Journal of Modern African Studies 38, 89-120.

Kidd, P.S., Parshall, M.B., 2000. Getting the focus and the group: Enhancing analytical rigor in focus group research. Qualitative Health Research 10, 293-308.

Kimiti, J., Esilaba, A., Vanlauwe, B., Bationo, A., 2007. Participatory Diagnosis in the Eastern Drylands of Kenya: Are Farmers aware of their Soil Fertility Status?, Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. Springer, pp. 961-968.

Klerkx, L., Aarts, N., Leeuwis, C., 2010. Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. Agricultural Systems 103, 390-400.

Klerkx, L., Hall, A., Leeuwis, C., 2009. Strengthening agricultural innovation capacity: Are innovation brokers the answer? International Journal of Agricultural Resources, Governance and Ecology 8, 409-438.

Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32, 25-48.

Kok, K., 2009. The potential of Fuzzy Cognitive Maps for semi-quantitative scenario development, with an example from Brazil. Global Environmental Change 19, 122-133.

Kolavalli, S., Kerr, J., 2002. Scaling up participatory watershed development in India. Dev. Change 33, 213-235.

Kolb, D.A., 1984. Experiential learning: Experience as the source of learning and development. Prentice-Hall Englewood Cliffs, NJ.

Koohafkan, P., Altieri, M.A., Holt Gimenez, E., 2012. Green Agriculture: Foundations for biodiverse, resilient and productive agricultural systems. International Journal of Agricultural Sustainability 10, 61-75.

Kraaijvanger, R., 2013. PE&RC-08060-Working document I: Phase (2008-2009). Available under: http://edepot.wur.nl/259130.

Kraaijvanger, R., 2015a. PE&RC-08060-Working document II: Interviews. Available under http://edepot.wur.nl/358070.

Kraaijvanger, R., 2015b. PE&RC-08060 Working Document III: Phase 1 (2008-2009 updated). Available under: http://edepot.wur.nl/366007.

Kraaijvanger, R., Almekinders, C.J.M., Veldkamp, A., 2016a. Identifying crop productivity constraints and opportunities using focus group discussions: A case study with farmers from Tigray. NJAS - Wageningen Journal of Life Sciences 78, 139-151.

Kraaijvanger, R., Sonneveld, M., Almekinders, C., Veldkamp, T., 2015. Comparison of methods to identify crop productivity constraints in developing countries. A review. Agronomy for Sustainable Development 35, 625-637.

Kraaijvanger, R., Veldkamp, A., 2015a. The importance of local factors and management in determining wheat yield variability in on-farm experimentation in Tigray, northern Ethiopia. Agriculture, Ecosystems and Environment 214, 1-9.

Kraaijvanger, R., Veldkamp, T., 2015b. Grain Productivity, Fertilizer Response and Nutrient Balance of Farming Systems in Tigray, Ethiopia: A Multi-Perspective View in Relation to Soil Fertility Degradation. Land Degradation & Development 26, 701-710.

Kraaijvanger, R., Veldkamp, T., Almekinders, C., 2016b. Considering change: Evaluating four years of participatory experimentation with farmers in Tigray (Ethiopia) highlighting both functional and human–social aspects. Agricultural Systems 147, 38-50.

Kraaijvanger, R., Witteveen, L., 2018. Farmer responsibility and researcher learning: Two sides of the same coin? Reflecting on five years of involvement in participatory experimentation in Tigray, Northern Ethiopia. International Journal of Agricultural Extension, 01-18.

Kraaijvanger, R.G., Veldkamp, T., 2017. Four years of farmer experimentation on soil fertility in Tigray, northern Ethiopia: trends in research strategies. The Journal of Agricultural Education and Extension, 1-19.

Lanckriet, S., Araya, T., Derudder, B., Cornelis, W., Bauer, H., Govaerts, B., Deckers, J., Haile, M., Naudts, J., Nyssen, J., 2014. Toward Practical Implementation of Conservation Agriculture: A Case Study in the May Zeg-zeg Catchment (Ethiopia). Agroecology and Sustainable Food Systems.

Lançon, J., Wery, J., Rapidel, B., Angokaye, M., Gérardeaux, E., Gaborel, C., Ballo, D., Fadegnon, B., 2007. An improved methodology for integrated crop management systems. Agronomy for Sustainable Development 27, 101-110.

Landon, J.R., 1991. Booker tropical soil manual : a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, Harlow.

Leeuwis, C., 2000. Reconceptualizing Participation for Sustainable Rural Development: Towards a Negotiation Approach. Development and Change 31, 931-959.

Leeuwis, C., Aarts, N., 2011. Rethinking communication in innovation processes: Creating space for change in complex systems. Journal of Agricultural Education and Extension 17, 21-36.

Leitgeb, F., Funes-Monzote, F.R., Kummer, S., Vogl, C.R., 2011. Contribution of farmers' experiments and innovations to Cuba's agricultural innovation system. 26, 354-367.

Leitgeb, F., Kummer, S., Funes-Monzote, F.R., Vogl, C.R., 2014. Farmers' experiments in Cuba. Renewable Agriculture and Food Systems 29, 48-64.

Lesschen, J.P., Stoorvogel, J.J., Smaling, E.M.A., Heuvelink, G.B.M., Veldkamp, A., 2007. A spatially explicit methodology to quantify soil nutrient balances and their uncertainties at the national level. Nutrient Cycling in Agroecosystems 78, 111-131.

Longhurst, R., Lipton, M., 1989. The role of agricultural research and secondary food crops in reducing seasonal food security. Seasonal variability in Third World agriculture, 285-297.

Love, D., Twomlow, S., Mupangwa, W., Van der Zaag, P., Gumbo, B., 2006. Implementing the millennium development food security goals- Challenges of the southern African context. Physics and Chemistry of the Earth 31, 731-737.

Maat, H., 2011. The history and future of agricultural experiments. NJAS - Wageningen Journal of Life Sciences 57, 187-195.

Mancini, F., 2006. Impact of Integrated Pest Management Farmer Fields Schools on health, farming systems, the environment, and livelihoods of cottongrowers in Southern India, Biological Farming Systems. Wageningen University, Wageningen, p. 108.

Mapfumo, P., Adjei-Nsiah, S., Mtambanengwe, F., Chikowo, R., Giller, K.E., 2013. Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. Environmental Development 5, 6-22.

Marquardt, K., Salomonsson, L., Geber, U., 2009. Farmers facing rapid agricultural land condition changes in two villages in the Upper Amazon, Peru: Can action learning contribute to resilience? International Journal of Agricultural Resources, Governance and Ecology 8, 457-483.

Martin, A., Sherington, J., 1997. Participatory Research Methods-Implementation, Effectiveness and Institutional Context. Agricultural Systems 55, 195-216.

Matsuo, M., 2015. A Framework for Facilitating Experiential Learning. Human Resource Development Review 14, 442-461.

Mayoux, L., Chambers, R., 2005. Reversing the paradigm: quantification, participatory methods and pro-poor impact assessment. Journal of International Development 17, 271-298.

McCann, J.C., 1995. People of the Plow. An Agricultural History of Ethiopia, 1800-1990. The University oif Wisconsin Press, London.

McIntyre, B.D., Herren, H.R., Wakhungu, J., Watson, R.T., 2009. Agriculture at a Crossroads. International assessment of agricultural knowledge, science and technology for development (IAASTD): Synthesis Report. Island Press, Washington DC.

Mengel, K., Kirkby, E.A., 1987. Principles of plant nutrition. International Potash Institute, Worblaufen-Bern.

Misiko, M., 2009. Collective experimentation: Lessons from the field. Journal of agricultural education and extension 15, 401-416.

Misiko, M., 2013. Dilemma in participatory selection of varieties. Agricultural Systems 119, 35-42.

Misiko, M., Tittonell, P., Giller, K.E., Richards, P., 2011. Strenghtening understanding and perceptions of mineral fertilizer use among smallholder farmers: evidence from collective trials in western kenya. Agriculture and Human Values 28, 27-38.

Misiko, M., Tittonell, P., Ramisch, J.J., Richards, P., Giller, K.E., 2008. Integrating new soybean varieties for soil fertility management in smallholder systems through participatory research: Lessons from western Kenya. Agricultural Systems 97, 1-12.

Morris, M.L., Bellon, M.R., 2004. Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. Euphytica 136, 21-35.

Mosse, D., 2001. "People's Knowledge", Participation and Patronage: Operations and Representations in Rural Development, in: Cooke, B., Kothari, U. (Eds.), Participation: The New Tyranny ? Zed Books, London.

Mowo, J.G., Janssen, B.H., Oenema, O., German, L.A., Mrema, J.P., Shemdoe, R.S., 2006. Soil fertility evaluation and management by smallholder farmer communities in northern Tanzania. Agriculture, Ecosystems and Environment 116, 47-59.

Mudege, N.N., Nyekanyeka, T., Kapalasa, E., Chevo, T., Demo, P., 2015. Understanding collective action and women's empowerment in potato farmer groups in Ntcheu and Dedza in Malawi. Journal of Rural Studies 42, 91-101.

Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N., Foley, J.A., 2012. Closing yield gaps through nutrient and watermanagement. Nature 490, 254-257.

Mugwe, J., Mugendi, D., Kungu, J., Muna, M.M., 2009. Maize yields response to application of organic and inorganic input under on-station and on-farm experiments in central Kenya. Experimental Agriculture 45, 47-59.

Murphy, H.F., 1959. A report on the fertility status of some soils of Ethiopia. , Experimental Station Bulletin No. 1. Imperial Ethiopian College of Agriculture and Mechanical Arts, Alemaya, Ethiopia.

Musvoto, C., Mason, N., Jovanovic, N., Froebrich, J., Tshovhote, J., Nemakhavhani, M., Khabe, T., 2015. Applying a transdisciplinary process to define a research agenda in a smallholder irrigated farming system in South Africa. Agricultural Systems 137, 39-50.

N2Africa, 2016. http://www.n2africa.org/. Accessed: 25-11-2016.

Ndekha, A., Hansen, E.H., Mølgaard, P., Woelk, G., Furu, P., 2003. Community participation as an interactive learning process: Experiences from a schistosomiasis control project in Zimbabwe. Acta Tropica 85, 325-338.

Nederlof, E.S., Tossou, R., Sakyi-Dawson, O., Kossou, D.K., 2004. Grounding agricultural research in resource-poor farmers' needs: A comparative analysis of diagnostic studies in Ghana and Benin. NJAS - Wageningen Journal of Life Sciences 52, 421-442.

Neef, A., Neubert, D., 2011. Stakeholder participation in agricultural research projects: A conceptual framework for reflection and decision-making. Agriculture and Human Values 28, 179-194.

Negash, Z., Nega, F., Gebreezgabiabher, K., Ejigu, A., Berhanu, M., Nyssen, J., Babulo, B., Deckers, J., Tollens, E., 2006. Manual for Participatory Rural Appraisal (PRA) in Villages of Tigray. Tigray Livelihood Papers 1, 64.

NEN, 2014. NEN 5754 Calculation of organic matter content on a mass basis as loss-on-ignition (in dutch). National Committee for Environmental Quality, Delft.

Norman, M.J.T., Pearson, C.J., Searle, P.G.E., 1995. Tropical food crops in their environment. Cambridge University Prss, Cambridge.

Nyssen, J., Govaerts, B., Araya, T., Cornelis, W., Bauer, H., Haile, M., Sayre, K., Deckers, J., 2011. The use of the marasha ard plough for conservation agriculture in Northern Ethiopia. Agronomy and Sustainable Development 31, 287-297.

Nyssen, J., Haregeweyn, N., Descheemaeker, K., Gebremichael, D., Vancampenhout, K., Poesen, J., Haile, M., Moeyersons, J., Buytaert, W., Naudts, J., Deckers, J., Govers, G., 2006. Comment on "Modelling the effect of soil and water conservation practices in Tigray, Ethiopia" [Agric. Ecosyst. Environ. 105 (2005) 29-40]. Agriculture, Ecosystems and Environment 114, 407-411.

Nyssen, J., Poesen, J., Moeyersons, J., Deckers, J., Haile, M., Lang, A., 2004. Human impact on the environment in the Ethiopian and Eritrean highlands - A state of the art. Earth Sci. Rev. 64, 273-320.

Nyssen, J., Vandenreyken, H., Poesen, J., Moeyersons, J., Deckers, J., Haile, M., Salles, C., Govers, G., 2005. Rainfall erosivity and variability in the Northern Ethiopian Highlands. Journal of Hydrology 311, 172-187.

Odera, M., Kimani, S., Esilaba, A., Kaiyare, J., Mwangi, E., Gachanja, E., 2007. Factors determining integrated soil fertility management in central Kenya highlands: Participatory Learning and Action (PLAR) model analysis, Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. Springer, pp. 1019-1026.

Okalebo, J., Gathua, K., Woomer, P., 2002. Laboratory methods of plant and soil analysis: a working manual. Tropical Soil Biology and Fertility Programme, Nairobi.

Okali, C., Sumberg, J., Farrington, J., 1994. Farmer participatory research : rhetoric and reality. Intermediate Technology Publications, London.

Onwuegbuzie, A.J., Dickinson, W.B., Leech, N.L., Zoran, A.G., 2009a. A Qualitative Framework for Collecting and Analyzing Data in Focus Group Research. International Journal of Qualitative Methods 8, 1-21.

Onwuegbuzie, A.J., Johnson, R.B., Collins, K.M.T., 2009b. Call for mixed analysis: A philosophical framework for combining qualitative and quantitative approaches. International Journal of Multiple Research Approaches 3, 114-139.

Page, A.L., Dinauer, R.C., 1982. Methods of soil analysis: Chemical and microbiological properties. American Society of Agronamy, Madison.

Parfitt, T., 2004. The ambiguity of participation: a qualified defence of participatory development. Third World Quarterly 25, 537-555.

Pascual, M., Miñana, E.P., Giacomello, E., 2016. Integrating knowledge on biodiversity and ecosystem services: Mind-mapping and Bayesian Network modelling. Ecosystem Services 17, 112-122.

Patrick, B.C., Hisley, J., Kempler, T., 2000. "What's everybody so excited about?": The effects of teacher enthusiasm on student intrinsic motivation and vitality. Journal of Experimental Education 68, 217-236.

Peterson, A.R., Snyder, P.J., 1998. Using Mind Maps To Teach Social Problems Analysis. ERIC.

Poteete, A.R., Ostrom, E., 2004. Heterogeneity, group size and collective action: The role of institutions in forest management. 35, 435-461.

Pretty, J.N., 1995. Participatory learning for sustainable agriculture. World Development 23, 1247-1263.

Prince, M., 2004. Does active learning work? A review of the research. Journal of engineering education 93, 223-231.

Probst, K., 2002. Participatory Monitoring and Evaluation: A promising Concept in Participatory Research ? Margraf Verlag, Weikersheim.

Raman, A., Ladha, J.K., Kumar, V., Sharma, S., Piepho, H.P., 2011. Stability analysis of farmer participatory trials for conservation agriculture using mixed models. Field Crops Research 121, 450-459.

Ramisch, J., 2012. This field is our church, in: Sumberg, J., Thompson, J. (Eds.), Contested agronomy: agricultural research in a changing world. New York and London: . Earthscan/Routledge, New York.

Ramisch, J.J., 2014. 'They don't know what they are talking about': Learning from the dissonances in dialogue about soil fertility knowledge and experimental practice in western Kenya. Geoforum 55, 120-132.

Ramisch, J.J., Misiko, M.T., Ekise, I.E., Mukalama, J.B., 2006. Strengthening ‘folk ecology’: community-based learning for integrated soil fertility management, western Kenya. International Journal of Agricultural Sustainability 4, 154-168.

Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M., Evely, A.C., 2010. Integrating local and scientific knowledge for environmental management. Journal of Environmental Management 91, 1766-1777.

Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. Biological Conservation 141, 2417-2431.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management 90, 1933-1949.

Richards, P., 1986. Coping with hunger. Hazard and experiment in an African rice-farming system. Allen & Unwin, London.

Richards, P., De Buin-Hoekzema, M., Hughes, S.G., Kudadjie-Freeman, C., Offei, S.K., Struik, P.C., Zannou, A., 2009. Seed systems for African food security: linking molecular genetic analysis and cultivator kbowledge in West Africa. International Journal of Technology Management 45, 196-214.

Rigolot, C., de Voil, P., Douxchamps, S., Prestwidge, D., Van Wijk, M., Thornton, P., Rodriguez, D., Henderson, B., Medina, D., Herrero, M., 2017. Interactions between intervention packages, climatic risk, climatic change and food security in mixed crop-livestock systems in Burkina Faso. Agricultural Systems 151, 217-224.

Riley, J., Alexander, C.J., 1997. Statistical literature for participatory on-farm research. Experimental Agriculture 33, 73-82.

Rocheleau, D.E., 1994. Participatory research and the race to save the planet: Questions, Critique, and Lessons from the field. Agriculture and Human Values 11, 4-25.

Röling, N., Jiggins, J., Hounkonnou, D., Van Huis, A., 2014. Agricultural research - from recommendation domains to arenas for interaction: Experiences from West Africa. Outlook on Agriculture 43, 179-185.

Röling, N.G., Hounkonnou, D., Offel, S.K., Tossou, R., Van Huis, A., 2004. Linking science and farmers' innovative capacity: Diagnostic studies from Ghana and Benin. NJAS - Wageningen Journal of Life Sciences 52, 211-235.

Romina, R., 2014. Social learning, natural resource management, and participatory activities: A reflection on construct development and testing. NJAS - Wageningen Journal of Life Sciences 69, 15-22.

Ronner, E., 2018. From Targeting to Tailoring. Baskets of options for legume cultivation among African smallholders., Plant Production Systems. Wageningen University, Wageningen.

Rufino, M.C., Tittonell, P., van Wijk, M.T., Castellanos-Navarrete, A., Delve, R.J., de Ridder, N., Giller, K.E., 2007. Manure as a key resource within smallholder farming systems: Analysing farm-scale nutrient cycling efficiencies with the NUANCES framework. Livestock Science 112, 273-287.

Rurinda, J., 2014. Vulnerability and Adaptation to Climate Variability and Change in Smallholder Farming Sysyems in Zimbabwe, Plant Production Systems. Wageningen University, Wageningen, p. 177.

Ryan, J., 2008. Crop nutrients for sustainable agricultural production in the drought-stressed mediterranean region. Journal of Agricultural Science and Technology 10, 295-306.

Sabates-Wheeler, R., Devereux, S., 2010. Cash transfers and high food prices: Explaining outcomes on Ethiopia’s Productive Safety Net Programme. Food Policy 35, 274-285.

Sahn, D.E., Stifel, D.C., 2003. Progress toward the millenium development goals in Africa. World Development 31, 23-52.

Sanchez, P.A., Swaminathan, M.S., 2005. Hunger in Africa: the link between unhealthy people and unhealthy soils. The Lancet 365, 442-444.

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L.C., Raboanarielina, C.M., Adegbola, P.Y., van Ast, A., Bastiaans, L., 2015a. RAAIS: Rapid Appraisal of

Agricultural Innovation Systems (Part 1). A diagnostic tool for integrated analysis of complex problems and innovation capacity. Agricultural Systems 132, 1-11.

Schut, M., Klerkx, L., Sartas, M., Lamers, D., Campbell, M., Ogbonna, I., Kaushik, P., Atta-Krah, K., Leeuwis, C., 2015b. Innovation platforms: experiences with their institutional embedding in agricultural research for developement. Experimental Agriculture, 1-25.

Scogings, B., Ngubane-Shezi, N., Shezi, Z., 2009. Supporting or enhancing local innovation as a tool for ensuring the sustainable use of natural resources. Available under: http://www.prolinnova.net/~prolin/sites/default/files/documents/S_Africa/2009/scogings_et_al_landcare_2009.doc. Accessed 14-04-2014.

Scoones, I., Wolmer, W., 2003. Introduction: Livelihoods in crisis: Challenges for rural development in Southern Africa. IDS Bull. 34, 1-14.

Segers, K., Dessein, J., Nyssen, J., Haile, M., Deckers, J., 2008. Developers and farmers intertwining interventions: The case of rainwater harvesting and food-for-work in Degua Temben, Tigray, Ethiopia. International Journal of Agricultural Sustainability 6, 173-182.

Shahvali, M., Zarafshani, K., 2002. Using PRA techniques as metacognitive strategies to develop indigenous knowledge - A case study. International Social Science Journal 54, 413-419.

Sharma, A.K., 2002. Biofertilizers for Sustainable Agriculture, first ed. Agrobios India, Jadhpur, India.

Sherman, M.H., Ford, J., 2014. Stakeholder engagement in adaptation interventions: An evaluation of projects in developing nations. Climate Policy 14, 417-441.

Shiferaw, B.A., Okello, J., Reddy, R.V., 2009. Adoption and adaptation of natural resource management innovations in smallholder agriculture: Reflections on key lessons and best practices. Environment, Development and Sustainability 11, 601-619.

Siyoum, A.D., 2012. Broken Promises (Food Security Interventions and Rural Livelihoods in Ethiopia), Disaster Studies. Wageningen University, Wageningen, the Netherlands, p. 172.

Smajgl, A., Ward, J., 2015. Evaluating participatory research: Framework, methods and implementation results. Journal of Environmental Management 157, 311-319.

Smaling, E.M.A., Fresco, L.O., De Jager, A., 1996. Classifying, monitoring and improving soil nutrient stocks and flows in african agriculture. AMBIO 25, 492-496.

Sperling, L., Ashby, J.A., Smith, M.E., Weltzien, E., McGuire, S., 2001. A framework for analyzing participatory plant breeding approaches and results. Euphytica 122, 439-450.

Spielman, D.J., Byerlee, D., SAlemu, D., Kelemework, D., 2010. Policies to promote cereal intensification in Ethiopia: The search for appropriate public and private roles. Food Policy 35, 185-194.

Spielman, D.J., Ekboir, J., Davis, K., Ochieng, C.M.O., 2008. An innovation system perspective on strengtening agricultural education and training in sub-Saharan Africa. Agricultural Systems 98, 1-9.

Staver, C., Bustamante, O., Siles, P., Aguilar, C., Quinde, K., Castellón, J., Somarriba, F., Tapia, A., Brenes, S., Deras, M., Matute, N., 2013. Intercropping bananas with coffee and trees: Prototyping agroecological intensification by farmers and scientists. Acta Horticulturae 986, 79-86.

Stoorvogel, J.J., Smaling, E.M.A., Janssen, B.H., 1993. Calculating soil nutrient balances in Africa at different scales - I Supra-national scale. Fertilizer Research 35, 227-235.

Stroosnijder, L., 2003. Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa, Symposium and Workshop Technologies for Improving Green Water Use Efficiency in West Africa, Bloemfontein, South Africa, pp. 8-11.

Sturdy, J.D., Jewitt, G.P.W., Lorentz, S.A., 2008. Building an understanding of water use innovation adoption processes through farmer-driven experimentation. Physics and Chemistry of the Earth 33, 859-872.

Suchiradipta, B., Ray, S., 2015. Agricultural Innovation Systems (AIS): A Study of Stakeholders and their Relations in Systems of Rice Intensification (SRI). Journal of Agricultural Education and Extension 21, 343-368.

Sumberg, J., 2005. Constraints to the adoption of agricultural innovations: Is it time for a re-think? Outlook on Agriculture 34, 7-10.

Sumberg, J., Okali, C., Reece, D., 2003. Agricultural research in the face of diversity, local knowledge and the participation imperative: Theoretical considerations. Agricultural Systems 76, 739-753.

Sustainable-Development, 2015. http://www.sustainabledevelopment2015.org/index.php/news/284-news-sdgs/1616-owg-on-sdgs-concludes-with-critical-outcome-document. Accessed 29-09-2016.

Teklewold, H., Kassie, M., Shiferaw, B., 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. Journal of Agricultural Economics 64, 597-623.

Tittonell, P., Giller, K.E., 2013. When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. Field Crops Research 143, 76-90.

Tittonell, P., Scopel, E., Andrieu, N., Posthumus, H., Mapfumo, P., Corbeels, M., van Halsema, G.E., Lahmar, R., Lugandu, S., Rakotoarisoa, J., Mtambanengwe, F., Pound, B., Chikowo, R., Naudin, K., Triomphe, B., Mkomwa, S., 2012. Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. Field Crops Research 132, 168-174.

Tittonell, P., Vanlauwe, B., Corbeels, M., Giller, K.E., 2008. Yield gaps, nutrient use efficiencies and response to fertilisers by maize across heterogeneous smallholder farms of western Kenya. Plant and Soil 313, 19-37.

Totin, E., Stroosnijder, L., Agbossou, E., 2013. Mulching upland rice for efficient water management: A collaborative approach in Benin. Agricultural Water Management 125, 71-80.

Totin, E., van Mierlo, B., Mongbo, R., Leeuwis, C., 2015. Diversity in success: Interaction between external interventions and local actions in three rice farming areas in Benin. Agricultural Systems 133, 119-130.

Trenkner, L.L., Achterberg, C.L., 1991. Use of focus groups in evaluating nutrition education materials. Journal of the American Dietetic Association 91, 1577-1581.

Trimble, M., Lázaro, M., 2014. Evaluation criteria for participatory research: Insights from coastal Uruguay. Environmental Management 54, 122-137.

Trouche, G., Lançon, J., Aguirre Acuna, S., Castro Briones, B., Thomas, G., 2012. Compoaring decentralized participatory breeding with on-station conventional sorghum breeding in Nicaragua: II Farmer acceptance and index of global value. Fields Crop Research 126, 70-78.

Tsegay, A., 2012. Improving crop production by field management strategies using crop water productivity modeling: Case study of tef (Eragrostis tef (Zucc.) Trotter) production in Tigray, Ethiopia, Faculty of Bioscience Engineering. Katholieke Universiteit Leuven, Leuven, p. 186.

Tumbo, S.D., Mutabazi, K.D., Byakugila, M.M., Mahoo, H.F.M., 2011. An empirical framework for scaling-out of water system innovations: Lessons from diffusion of water system innovations in the Makanya catchment in Northern Tanzania. Agricultural Water Management 98, 1761-1773.

UN, 2015. Millenium Development Goals Report 2015. United Nations, New York.

Uzunlu, V., Bayaner, A., Beniwal Icarda, S.P.S., 1999. Problem identification and priority setting in agricultural research: The case of the Eastern Margin of Central Anatolia. Turkish Journal of Agriculture and Forestry 23, 679-686.

Van Asten, P.J.A., Kaaria, S., Fermont, A.M., Delve, R.J., 2009. Challenges and lessons when using farmer knowledge in agricultural research and development projects in Africa. Experimental Agriculture 45, 1-14.

Van De Fliert, E., 2003. Recognising a climate for sustainability: Extension beyond transfer of technology. Australian Journal of Experimental Agriculture 43, 29-36.

Van De Fliert, E., Braun, A.R., 2002. Conceptualizing integrative, farmer participatory research for sustainable agriculture: From opportunities to impact. Agriculture and Human Values 19, 25-38.

Van de Wauw, J., Baert, G., Moeyersons, J., Nyssen, J., De Geyndt, K., Taha, N., Zenebe, A., Poesen, J., Deckers, J., 2008. Soil-landscape relationships in the basalt-dominated highlands of Tigray, Ethiopia. Catena 75, 117-127.

Van der Veen, A., Tagel, G., 2011. Effect of Policy Interventions on Food Security in Tigray, Northern Ethiopia. Ecology and Society 16, article 18.

Van Der Wal, M., De Kraker, J., Offermans, A., Kroeze, C., Kirschner, P.A., van Ittersum, M., 2014. Measuring social learning in participatory approaches to natural resource Management. 24, 1-15.

van Groenigen, J.W., Gandah, M., Bouma, J., 2000. Soil Sampling Strategies for Precision Agriculture Research under Sahelian Conditions. Soil Science Society of America Journal 64, 1674-1680.

Van Ittersum, M.K., Cassman, K.G., Grassini, P., Wolf, J., Tittonell, P., Hochman, Z., 2013. Yield gap analysis with local to global relevance-A review. Field Crops Research 143, 4-17.

Van Mele, P., 2008. The importance of ecological and socio-technological literacy in R&D priority setting: The case of a fruit innovation system in Guinea, West Africa. International Journal of Agricultural Sustainability 6, 183-194.

van Mierlo, B., Leeuwis, C., Smits, R., Klein Woolthuis, R., 2010. Learning towards system innovation: Evaluating a systemic instrument. Technological Forecasting & Social Change 77, 318-334.

van Noordwijk, M., Brussaard, L., 2014. Minimizing the ecological footprint of food: Closing yield and efficiency gaps simultaneously? Current Opinion in Environmental Sustainability 8, 62-70.

van Reeuwijk, L.P., 2002. Procedures for soil analysis, 6th edition. ISRIC, Wageningen.

Van Rijn, F., Bulte, E., Adekunle, A., 2012. Social capital and agricultural innovation in Sub-Saharan Africa. Agricultural Systems 108, 112-122.

Van Vliet, M., Kok, K., Veldkamp, T., Sarkki, S., 2012. Structure in creativity: An exploratory study to analyse the effects oif structuring tools on scenario workshop results. Futures 44, 746-760.

Vancampenhout, K., Nyssen, J., Gebremichael, D., Deckers, J., Poesen, J., Haile, M., Moeyersons, J., 2006. Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. Soil and Tillage Research 90, 1-15.

Vandeplas, I., 2010. Farmer & Researcher Collaboration for Pro-Poor Development, through soybean production. A case study in SW-Kenya., Earth and Environmental Sciences. KU-Leuven, Leuven.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L., Sanginga, N., 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. Outlook on Agriculture 39, 17-24.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., Six, J., 2011. Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. Plant and Soil 339, 35-50.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B., Nolte, C., 2014. A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. 155, 10-13.

Veldkamp, A., Kok, K., De Koning, G.H.J., Schoorl, J.M., Sonneveld, M.P.W., Verburg, P.H., 2001a. Multi-scale system approaches in agronomic research at the landscape level. Soil and Tillage Research 58, 129-140.

Veldkamp, A., Van Altvorst, A.C., Eweg, R., Jacobsen, E., Van Kleef, A., Van Latesteijn, H., Mager, S., Mommaas, H., Smeets, P.J.A.M., Spaans, L., Van Trijp, J.C.M., 2009. Triggering transitions towards sustainable development of the Dutch agricultural sector: TransForum's approach. Agronomy for Sustainable Development 29, 87-96.

Veldkamp, A., Verburg, P.H., Kok, K., De Koning, G.H.J., Priess, J., Bergsma, A.R., 2001b. The need for scale sensitive approaches in spatially explicit land use change modeling. Environ. Model. Assess. 6, 111-121.

Virgo, K.J., Munro, R.N., 1978. Soil and erosion features of the central plateau region of Tigrai, Ethiopia. Geoderma 20, 131-157.

Waddington, S.R., Li, X., Dixon, J., Hyman, G., de Vicente, M.C., 2010. Getting the focus right: Production constraints for six major food crops in Asian and African farming systems. Food Security 2, 27-48.

Waldman, K.B., Kerr, J.M., Isaacs, K.B., 2014. Combining participatory crop trials and experimental auctions to estimate farmer preferences for improved common bean in Rwanda. Food Policy 46, 183-192.

Wani, S.P., Chander, G., Sahrawat, K.L., 2014. Science-led interventions in integrated watersheds to improve smallholders' livelihoods. NJAS - Wageningen Journal of Life Sciences 70, 71-77.

Wenger, E., 2000. Communities of practice and social learning systems. Organization 7, 225-246.

Wentzel, K.R., Battle, A., Russell, S.L., Looney, L.B., 2010. Social supports from teachers and peers as predictors of academic and social motivation. Contemporary Educational Psychology 35, 193-202.

Werner, D., Thumann, C., Maxwell, J., Pearson, A., 2001. Where there is no doctor (for Ethiopia), a village health care handbook. Shama Books, Addis Abeba.

Westphal, E., 1975. Agricultural systems in Ethiopia. Centre for Agricultural Publishing and Documentation, Wageningen.

Wigboldus, S., Klerkx, L., Leeuwis, C., Schut, M., Muilerrman, S., Jochemsen, H., 2016. Systemic perspectives on scaling agricultural innovations. A review. Agronomy and Sustainable Development 36:46.

Williams, G., 2004. Evaluating participatory development: tyranny, power and (re) politicisation. Third World Quarterly 25, 557-578.

Woldewahid, G., Gebremedhin, B., Berhe, K., Hoekstra, D., 2011. Shifting towards market-oriented irrigated crops development as an approach to improve income of farmers: Evidence from northern Ethiopia, IPMS Ethiopian Farmers Project Working Paper 28. ILRI, Nairobi, Kenya.

Wood, B.A., Blair, H.T., Gray, D.I., Kemp, P.D., Kenyon, P.R., Morris, S.T., Sewell, A.M., 2014. Agricultural science in the wild: A social network analysis of farmer knowledge exchange. PLoS ONE 9.

Worldbank, 2007. World development report 2008: Agriculture for development. The Worldbank, Washington DC, USA.

Yami, M., 2016. Irrigation projects in Ethiopia: what can be done to enhance effectiveness under 'challenging contexts'? International Journal of Sustainable Development and World Ecology 23, 132-142.

Yami, M., Mekuria, W., Hauser, M., 2013. The effectiveness of village bylaws in sustainable management of community-managed exclosures in Northern Ethiopia. Sustainability Science 8, 73-86.

Yami, M., Vogl, C., Hauser, M., 2011. Informal institutions as mechanisms to address challenges in communal grazing land management in Tigray, Ethiopia. International Journal of Sustainable Development and World Ecology 18, 78-87.

Zhang, B., Zhang, Y., Chen, D., White, R.E., Li, Y., 2004. A quantitative evaluation system of soil productivity for intensive agriculture in China. Geoderma 123, 319-331.

Zingore, S., Murwira, H.K., Delve, R.J., Giller, K.E., 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture, Ecosystems and Environment 119, 112-126.

Summary

Crop productivity and food security are important concerns in relation to development and stability of rural communities. Nations, in general, aim at achieving food security. India and China, for example, used the high-external-input-paradigms of the Green Revolution to achieve highly productive agriculture. Still, in sub-Saharan Africa (SSA), like in many other parts of the world, problems with food security and crop production are manifest, and low agricultural productivity is restricting the development of rural economies. Contrasting to other parts of the world, SSA did not achieve significant increase in crop yields. Constraints that limit crop yield are numerous, diffuse and rooted in a complex environmental and socioeconomic context. Much research effort was made, but adequate implementation of achieved results often was lacking. At the same time, farmers in many cases hesitated to adopt proposed technologies.

In Ethiopia, like in many other sub Saharan countries, agricultural productivity is low and production clearly is not covering national demands. In the years 2007-2009 about 10 % of the total cereal consumption was imported, whereas at the same time 43 % of the population was undernourished. In the years 2014-2016 the situation improved as the level of undernourishment dropped to 32%. In our study area, Tigray in Northern Ethiopia, official cereal production figures were reported ranging from 2279 kg/ha for maize, 1875 kg/ha for wheat and 1343 kg/ha for *teff* in 2013 . Yields achieved on farmer fields resulted, however, often in much lower figures. This low productivity is in most cases attributed to unreliability and shortage of rainfall in combination with problems like soil erosion, a low soil fertility, the incidence of pests and diseases and a low management level. Food security is in Tigray a persistent problem and many households depend for at least some part of the year on food support.

Tigray is mostly highland, with altitudes ranging from 1950 to over 2600 m. The landscape consists of sedimentary rocks, basalt flows and volcanic relicts. The landscape is, except for some relatively flat plateaus, in most places strongly dissected. Main soil types found are Cambisols, Luvisols, Vertisols and Leptosols. Most of Tigray can be considered as semi-arid drylands: maximum temperature ranges from 23 to 27 ^{o}C and the average annual precipitation ranges between 500

and 750 mm being distributed over a short and a long rainy season. Important crops are wheat, barley and *teff* and agricultural production mainly takes place in mixed farming systems.

A perspective for improving crop yields in Tigray can be provided in the form of upgrading and implementing technology with respect to soil, water and nutrient management. In our research project the objective of increasing crop yield was combined with the view that intentional involvement of farmers will support such transitions. In participatory approaches farmers and researchers collaborate to obtain understanding on possibilities to upgrade farming systems. Farmers involving in participatory experimentation are made responsible for the development of recommendations fitting with local conditions. Consequently, adoption of such recommendations will become more likely. In addition, farmers themselves are assumed to become more empowered and responsible for, and confident in their own development.

Participatory approaches in many cases are promoted extensively but only little is known about impact achieved in real-life settings. Our research project aimed to contribute to knowledge on participatory approaches by evaluating process and outcomes of a participatory research project in Tigray. Within an action research setting, farmers and researchers co-operated with the objective to improve crop yields. A central concern in our study was the impact achieved by participatory experimentation and more specifically the contributions participatory experimentation can make to intervention work. In our research project we focused on contributions resulting in change of farmers and their livelihoods with respect to both functional and human-social aspects. At a meta-level we aimed at an improved understanding of participatory experimentation and its outcomes in terms of process and causality.

In our research project 16 farmer groups were involved in participatory experimentation. These groups (each with about five members), came from four locations in Tigray and were over a period of four years involved in participatory experimentation. Data collection consisted of literature review, individual surveys, interviews with participants, focus group discussion, field measurements on inputs and crop yield and laboratory analysis of soils, crops and organic fertilizers.

Selecting a method for identifying actual crop productivity constraints is an important step in triggering innovation processes. Applied methods can be diverse and although such methods have consequences for the design of intervention strategies, documented comparisons between various methods are scarce. Different variables can be used to characterize these methods. In chapter 2 we used two of these variables to typify them in a heuristic model: *control over the research process* and *represented opinion*. We reviewed 16 published papers that presented outcomes of different methods to identify productivity constraints. The major findings were the following: (1) variation in methods is wide; (2) applying the heuristic model resulted in three main clusters of methods (farmer-control/farmer-opinion, scientist-control/scientist-opinion, scientist-control/farmer-opinion); (3) these clusters were scale level dependent.

As a follow up we compared in a case study three different methods, representative for the main clusters identified within the heuristic model, in order to assess their congruency. These methods (focus group discussion, individual surveys and contextual data collection) were applied in four localities in our study area. We found that congruency between the methods, as indicated by Spearman-ρ correlations, was not significant. In addition, we found that outcomes of individual surveys and contextual data collection among the different locations were highly correlated. No such correlation was found using focus group discussion. Both findings indicated that for a specific location, different methods yielded different constraints, and that variability between the locations was not reflected by using individual surveys and contextual data collection. Combined the review and case study demonstrated that *process control* and *represented opinion* had a manifest impact on outcomes generated. Because outcomes of productivity constraints assessments were methodology dependent researchers are recommended to justify *a priori* their choice of method using the presented heuristic model.

An essential step in development processes aiming at improving crop yield is the identification of constraints and opportunities. In chapter 3 we found that at macro- and mesolevel, diagnostic methods frequently pointed to soil fertility and agronomic practices as major constraints. In our study area we applied at four locations focus group discussion to identify productivity constraints and opportunities. Outcomes in the form of mind maps were quantified to allow comparison between the locations. We found that, apart from some similarities, outcomes demonstrated much diversity. Location specific conditions and agronomic factors were considered main constraints by farmer groups in all locations. Soil fertility measures were considered a main opportunity. Other categories of constraints and opportunities, like economic factors or irrigation, differed in perceived importance among the four locations. Outcome variability was supported by descriptive biophysical and socioeconomic data. We concluded that superficial identification of constraints and opportunities neglected contextual diversity. Making such diversity visible is essential in understanding and addressing this complexity. Applying approaches like focus group discussion at grassroots level at the same time offers important opportunities to give farmers a mandate and responsibility in early stages of development processes.

In chapter 4 outcomes of our participatory experimentation were presented. Objective of these participatory experiments was to arrive at recommendations matching with local preferences, complexity and context. In total 16 groups of farmers were involved in a participatory experimentation process during four years. The data resulting from the experiments were analysed using linear regression techniques. About 56% of the total grain yield variability in our experiments was explained by a linear regression model that included management , altitude and N-fertilizer input. When management was excluded from the model still 49% of the grain yield variability was explained by altitude, N-fertilizer input, N-total, organic-C, rainfall and K-exchangeable of the soil. This indicates that grain yield is very location specific and related to local climate and soil conditions. Excluding management, we found that straw productivity variability was explained for approximately 38% by including N-fertilizer input, the soil stoniness, soil-P content and the slope of the field as predictors. This indicates strong location variability but now also different soil properties mattered. Again excluding management, fertilizer responses were mainly explained by soil characteristics, which together with the inputs explained almost half of the total response variability.

Focusing specifically on the relation between different soil properties (organic-C, P and K) and response to recommended fertilizer application (of diammonium-phosphate and urea) we found this relation highly indifferent, but this was not the case for N-total. At the same time, also differences between recommended application and farmer managed fields, and between different treatments (sowing in rows, adding potassium and improving infiltration) were limited and non-significant. Our farmer participatory approach demonstrated why a one-size-fits-all strategy, i.e. blanket recommendations, will not work in Tigray. Both grain and straw production were determined by the complex local interplay of farmer management, soil properties, landscape and fertilizer input.

In chapter 5 we discussed the strategies farmer groups employed in designing their experiments. We found that farmers not only considered outcomes of previous years of experimentation but at the same time included insights based on the context of their farming system, their livelihood system and their experience. In the course of their involvement in participatory experimentation they more and more included own insights and diverged from the views held by scientists involved. At the same time, experimentation became more systematic, for example, by including controls and replications. Farmer groups were successful in their experimentation and achieved in the second year an average response of 84 % for their best three treatments. Due to frequent changes in fields and crops by the farmer groups this response was, however, not progressive and stabilized. Farmers included in their experiments treatments that achieved significant higher responses for straw than for grains. Also the optimal treatments they suggested appeared to focus on straw yield. Experimental results also resulted in significant response as compared to current practice, and therefore cannot be labelled simply *random* or *trial and error*.

The outcomes of farmer experimentation were in chapter 6 analysed by using different perspectives, the responses achieved and nutrient balances calculated. Three perspectives, embedded in the People-Planet-Profit framework, were considered. These perspectives differed in temporal scale, spatial scale and ownership. Taking a farmer perspective, we found no significant differences in response between recommended and current farmer practices. Taking an agronomist perspective, low phosphorus levels seemed to limit response to recommended fertilizer application. At the same time, it became obvious that closing nutrient balances at field scale in order to achieve sustainability, was difficult. Only by using considerable amounts of manure and at the cost of productivity this might be achieved. From a long-term environmentalist perspective, the traditional agricultural system, appeared sustainable by combining mixed farming with relatively low yields. We concluded that depending on the perspective taken, different interventions will be forwarded. Combining all three perspectives indicated that gradually strengthening the existing mixed farming system by using fertilizers, organic manure and legume-fallows will support different aspects of sustainability by increasing crop yield as well as food security and profitability. In line with this, our analysis of different perspectives suggested that in our study area farmers will only consider transitions with low risk and this should be respected in proposing pathways to transition. In processes where stakeholders with different perspectives co-operate it is important to be aware of and make use of the possibilities of multi-perspective analyses.

Participatory experimentation involving farmers and researchers often entails processes of experiential learning, and related to that, change. Processes of learning and change were essential in the context of our research project but are, in general, also difficult to grasp. In Chapter 7 we focused on observed and farmer-reported change with respect to functional and human-social aspects that might have resulted from involvement in participatory experimentation. Inputs from our side were intentionally minimized in order to allow maximum control over the process by the farmers and to avoid bias due to the provision of material incentives. Using data derived from interviews and further observations we documented changes and the participatory process to explore what changes had taken place and if these related to farmers' involvement. Farmers indicated that they gained knowledge and became confident with respect to agricultural practices like, for example, a more exact application of fertilizers. They also became more confident in systematic experimentation and achieved in most cases reasonable responses (> 50%). We also found that participants responded significantly different, in comparison to a control group: they would involve non-family more in their discussions about farm management, they would address officials more to solve neighbourhood problems, they would more likely debate with extension workers in relation to farm management and they had become more specific in their ambitions to learn about agriculture. Positive changes in relation to crop productivity and poverty were perceived by participants significantly more than by control group farmers. Participants, in general, considered their involvement worthwhile and highlighted as a main benefit mostly the aspect of learning. All 16 groups kept involved for four years and indicated to continue further on their own.

Evaluating a set of factors that might have influenced involvement we only found benefits in the form of reasonable responses being overall important. All other factors were highly variable among the groups and appeared to be trade-offs rather than knock-out factors. In designing processes of participatory experimentation it is therefore important to take such sets of impact factors into careful consideration. Given the diversity of groups and the context in which they operate it is not likely that blue-print approaches sufficiently address such variability.

Putting pieces, together we concluded that participatory experimentation contributed in different ways to functional and human-social change of the farmers involved. Contributions related, for example, to confidence, agricultural practice and yield and covered different livelihood capitals. Our involvement in this research project contributed to more understanding of participatory experimentation processes, and complexity of the agricultural system. Important insights related to the impact of choices throughout the process, sources of motivation, and responsibilities. Diversity of groups requires group-specific approaches and open processes in which the group and its functioning should stand central.

Rural transition processes in Tigray likely will benefit from participatory experimentation. Important aspects in this are its ability to generate context-specific outcomes, and possible contributions to functional and human-social change of the farmers involved. Important points in achieving this are: (1) delegating responsibilities to farmers in all phases of the process; (2) adequate facilitation of the process; (3) embedment of participatory experimentation in existing institutions and organizations; (4) operating at lower scale levels to secure both embedment in the community and relevant possibilities for scaling. Participatory experimentation in the context of Tigray, has as such the potential to act as a change agent and consequently might trigger transitions towards more sustainable livelihood systems.

Samenvatting

Gewasopbrengst en voedselzekerheid zijn belangrijk in verband met de ontwikkeling en stabiliteit van rurale gemeenschappen. Naties streven over het algemeen naar voedselzekerheid en landen zoals India en China gebruikten de *high input* uitgangspunten van de Groene Revolutie om tot een hoog productieve landbouw te komen. In andere delen van de wereld, zoals in sub Sahara Afrika (SSA) zijn problemen op het gebied van voedselzekerheid en gewasproductie nog steeds prominent aanwezig en lage gewasopbrengsten belemmeren er de ontwikkeling van de lokale economie. In tegenstelling tot andere delen van de wereld is in SSA de toename van gewasopbrengsten achter gebleven. De belemmeringen voor een hogere gewasproductiviteit zijn vaak veelvuldig en geworteld in de sociale, economische en biofysische context. Veel onderzoek werd reeds uitgevoerd, maar een adequate implementatie van de gevonden uitkomsten ontbreekt vaak; tegelijkertijd aarzelen boeren vaak om voorgestelde technologie te gebruiken.

In Ethiopië, zoals in veel andere landen in SSA is de gewasproductie laag en onvoldoende om de nationale behoefte af te dekken. In de jaren 2007-2009 werd ongeveer 10% van de totale graan consumptie geïmporteerd, tegelijkertijd was 43% van de bevolking ondervoed. In de jaren 2014-2016 daalde het ondervoedingspercentage naar 32%. In ons studiegebied, Tigray in Noord Ethiopië, waren de officiële cijfers voor graanproductie in 2013: 2279 kg/ha voor mais; 1875 kg/ha voor tarwe en 1343 kg/ha voor *teff*. Lokale opbrengsten op de bedrijven vallen echter vaak stukken lager uit. Deze lage productiviteit wordt veelal toegeschreven aan een geringe en onbetrouwbare regenval in combinatie met problemen zoals bodemerosie, uitgemergelde bodems, het optreden van ziektes en plagen en een laag management niveau. Voedselzekerheid is in Tigray een voortdurend probleem en veel huishoudens zijn nog steeds voor tenminste een deel van het jaar van voedselhulp afhankelijk.

Tigray is grotendeels hoogland tussen 1950 en 2600 m. Het landschap is opgebouwd uit sedimentgesteenten, basaltlagen en vulkanische relicten. Het landschap is, op wat vlakkere delen na, sterk geaccidenteerd. De belangrijkste bodemtypes zijn Cambisols, Luvisols, Vertisols en Leptosols. Tigray kan grotendeels als semi-aride *drylands* bestempeld worden: maximum temperaturen liggen tussen 23 -27 °C; de neerslag varieert tussen 500 en 750 mm en is verdeeld over een korte en een lange regentijd. Gemengde bedrijfssystemen domineren; de belangrijkste gewassen zijn tarwe, gerst en *teff*.

De standaardmethode om gewasopbrengsten te verhogen is meestal gebaseerd op het toepassen van verbeterde technologie met betrekking tot bodem, water en nutriëntenmanagement. In ons onderzoeksproject werd de doelstelling om de gewasopbrengsten te verbeteren gecombineerd met het uitgangspunt dat sterke betrokkenheid van boeren zulke transities kunnen bevorderen. In participatieve methoden werken boeren en onderzoekers samen om bijvoorbeeld inzicht te krijgen in de mogelijkheden om landbouwsystemen te verbeteren. Boeren welke betrokken zijn bij participatief onderzoek zijn medeverantwoordelijk voor de ontwikkeling van technologie en aanbevelingen welke aansluiten bij lokale omstandigheden. Als gevolg hiervan zal de adoptie van zulke technologie waarschijnlijker zijn; verder wordt aangenomen dat de betrokken boeren het heft meer in handen zullen nemen en zich verantwoordelijker voelen voor hun eigen ontwikkeling.

Participatieve methoden zijn in vele gevallen behoorlijk gepromoot, echter over de bereikte impact ervan in een *real-life* context is slecht weinig bekend. Ons onderzoeksproject had als doelstelling bij te dragen aan de kennis over participatieve methoden door proces en de uitkomsten van een participatief onderzoeksproject in Tigray te evalueren. In een *action research* context werkten boeren en onderzoekers samen met het doel gewasopbrengsten te verhogen. De centrale vraag in onze studie was na te gaan welke impact participatief onderzoek heeft en welke bijdrage participatief onderzoek kan leveren aan rurale ontwikkeling. In ons onderzoeksproject hebben we ons met name gericht op bijdragen van participatief onderzoek resulterend in verandering van boeren en hun bestaan met betrekking tot functionele en *human-social* aspecten. Op meta-niveau was een belangrijke doelstelling te komen tot een beter begrijpen van participatief onderzoek en de uitkomsten ervan in relatie tot proces en causaliteit.

In ons onderzoeksproject waren 16 boerengroepen betrokken bij participatief onderzoek. Deze groepen, elk met zo’n vijf deelnemers, kwamen uit vier deelgebieden in Tigray en waren voor een periode van vier jaar betrokken bij participatief onderzoek. Het verzamelen van data omvatte naast het uitvoeren van literatuur studie, individuele *surveys*, interviews met deelnemers en focus groep discussie ook opbrengstmetingen in het veld en laboratoriumbepalingen van eigenschappen van bodem, gewas en organische meststoffen.

Het selecteren van een methode om belemmeringen voor gewasproductiviteit vast te stellen is een belangrijke stap in het opstarten van innovatieve processen. De toegepaste methoden kunnen divers zijn. Ondanks het feit dat de keuze voor een specifieke methode gevolgen heeft voor het uiteindelijke ontwerp van de interventies zijn goed gedocumenteerde vergelijkingen tussen de verschillende methodes zeldzaam. Om deze identificatiemethoden te karakteriseren kunnen verschillende variabelen worden gebruikt. In hoofdstuk twee van deze thesis zijn twee specifieke variabelen gebruikt om in een heuristisch model deze identificatiemethoden te typeren: controle over het onderzoeksproces en gerepresenteerde opinie. We beschouwden 16 gepubliceerde artikelen waarin op basis van verschillende methoden belemmeringen voor gewasproductiviteit werden gepresenteerd. De belangrijkste uitkomsten waren de volgende: de variatie in gebruikte methoden is groot; het toepassen van het heuristische model resulteerde in drie verschillende clusters van methoden (de combinaties boerencontrole-boerenmening, onderzoekercontrole-onderzoekermening en onderzoekercontrole-boerenmening); deze clusters bleken sterk verweven met de schaal van de studie.

Aansluitend werden in een *case study* drie verschillende methoden welke de drie clusters uit het heuristische model representeerden vergeleken om hun eenduidigheid te onderzoeken. Deze methoden (focusgroep discussie, individuele *survey* en het gebruik van contextuele gegevens) werden toegepast in vier onderzoeklocaties binnen ons studiegebied. Op basis van *Spearman-ρ* correlaties kon geen eenduidigheid van de verschillende methoden worden aangetoond. Bovendien vonden we dat dat uitkomsten van de individuele *surveys* en het gebruik van contextuele data over de verschillende locaties sterk gecorreleerd waren en dat soortgelijke correlatie met beide andere methoden niet kon worden aangetoond voor focus groep discussie. Deze uitkomsten gaven aan dat voor een specifieke locatie de verschillende methoden verschillende belemmeringen aangaven en tevens dat variatie tussen locaties niet kon worden weergegeven bij het toepassen van individuele *surveys* en het gebruik van contextuele gegevens.

Samen lieten *review* en *casestudy* zien dat verschillen in controle over het proces en gerepresenteerde opinie een sterk bepalende invloed hadden op de gevonden uitkomsten. Omdat uitkomsten van onderzoek naar belemmerende factoren afhankelijk bleek te zijn van de toegepaste methode wordt onderzoekers aanbevolen vooraf de gekozen methodiek te typeren in het gepresenteerde heuristische model om mogelijke bias inzichtelijk te maken.

Een essentiële stap in ontwikkelingsprocessen welke zich richten op het verbeteren van gewasopbrengsten is het vaststellen van kansen en belemmeringen welke hierbij mogelijk een rol spelen. Diagnostische methoden op macro- en mesoniveau wijzen veelal naar de factoren bodemvruchtbaarheid en agronomische praktijk als belangrijkste belemmeringen. In ons studiegebied werd op vier locaties focusgroep discussie toegepast om mogelijke productiviteits-belemmeringen en kansen vast te stellen. In hoofdstuk 3 zijn discussie uitkomsten in de vorm van *mind maps* gekwantificeerd om een vergelijking tussen de vier locaties mogelijk te maken. We vonden dat, naast enige overeenkomst, uitkomsten zeer divers waren. Locatie-specifieke factoren en agronomische factoren werden door de betrokken boerengroepen in alle vier locaties als belangrijke belemmeringen aangeduid; bodemvruchtbaarheidsmaatregelen werden als een belangrijke kans gezien. Andere categoriën van kansen en belemmeringen, zoals economische factoren en irrigatie, verschilden sterk qua veronderstelde belangrijkheid over de vier locaties. De variatie in uitkomsten werd onderschreven door relevante sociaal-economische en biofysische data. We concludeerden dat een oppervlakkige identificatie van kansen en belemmeringen de invloed van een diverse context buiten beschouwing laat. Het toepassen van methoden zoals focusgroep discussie biedt daarnaast de mogelijkheid om boeren een mandaat en verantwoordelijkheid te geven in de startfase van ontwikkelingsprocessen.

In hoofdstuk 4 zijn de uitkomsten van het participatieve onderzoek gepresenteerd. De doelstelling van de uitgevoerde participatieve (veld)experimenten was te komen tot aanbevelingen welke aansluiten bij lokale voorkeuren, complexiteit en context. In totaal 16 boerengroepen waren betrokken bij veldexperimenten over een periode van vier jaar. De uitkomsten van de uitgevoerde experimenten zijn geanalyseerd met behulp van lineaire regressie technieken. Ongeveer 56% van de variatie in graanopbrengst kon worden verklaard door een regressie model bestaande uit de factoren management, hoogteligging en minerale stikstofgift. In het geval dat management buiten beschouwing werd gelaten kon nog steeds 49% van de variatie in graanopbrengst verklaard worden door hoogteligging, minerale stikstofgift, N-totaal in de bodem, organische koolstof gehalte van de bodem en het uitwisselbaar kalium gehalte van de bodem. Dit demonstreerde dat graanopbrengsten ten dele locatie specifiek zijn en aan het lokale klimaat en bodemtoestand gerelateerd zijn. Wederom management buiten beschouwing latend kon de variatie in stroproductiviteit voor 38% worden verklaard door de factoren minerale stikstofgift, stenigheid, fosfaatgehalte van de bodem en de steilheid van de helling en bleek wederom sprake van een sterk locatie afhankelijke variatie. Opnieuw zonder management te mee te nemen bleek respons van kunstmestgiften vooral door bodemeigenschappen te worden bepaald; deze verklaarden samen met de kunstmestgift de variatie in respons voor bijna de helft.

De relatie tussen een aantal bodemeigenschappen (organische koolstof, P en K) en respons voor de aanbevolen kunstmestgift beschouwend bleek dit verband in hoge mate onbepaald; dat was echter niet het geval voor N-totaal. Ook verschillen in opbrengst tussen aanbevolen kunstmestgift en percelen met boerenmanagement en de uitkomsten van specifieke experimenten (zaaien in rijen, het toevoegen van kalium en het verbeteren van infiltratie) waren beperkt en niet significant. De uitkomsten van de participatief ontworpen experimenten lieten zien dat een *one-size-fits-all* strategie op basis van algemene aanbevelingen voor kunstmestgiften niet zal werken in Tigray. Zowel graan- als stroproductie leken bepaald te worden door een complex samenspel op lokaal niveau van boerenmanagement, bodemeigenschappen, landschap en kunstmestgift.

De strategiën welke boeren groepen toepasten bij het ontwerpen van experimenten zijn het onderwerp van hoofdstuk 5. Boeren bleken niet alleen uitkomsten van voorgaande jaren mee te nemen maar gelijktijdig ook rekening te houden met inzichten gebaseerd op hun ervaring, het gebruikte bedrijfssysteem en de manier waarop ze in hun levensonderhoud voorzien. Gedurende de looptijd van het project namen de betrokken boeren steeds meer hun eigen inzichten mee en weken ze daarbij meer en meer af van inzichten van de betrokken onderzoekers. Gelijktijdig werd hun experimenteren systematischer, bijvoorbeeld, door nulmetingen en herhalingen in het ontwerp mee te nemen. Boerengroepen waren succesvol in hun experimenteren en bereikten in het tweede jaar een gemiddelde respons van 84% voor hun drie beste experimenten. Als gevolg van veranderingen in gebruikte percelen en gewassen bleef deze respons op een constant niveau en nam niet verder toe. In de boerenexperimenten bleek de respons voor stro-opbrengst significant hoger dan die voor graanopbrengst; ook de door de deelnemende boeren voorgestelde behandelingen leken meer op stro-opbrengst te focussen dan op die van graan. Uitkomsten van de experimenten lieten verder zien dat de bereikte respons in vergelijking met de actuele boerenpraktijk significant hoger was; een reden waarom deze niet als *random* of *trial and error* af gedaan kan worden.

De uitkomsten van boeren experimenten werden in hoofdstuk 6 geanalyseerd door verschillende perspectieven te gebruiken waarbij de bereikte respons en nutriëntenbalansen beschouwd werden. De beschouwde perspectieven (boer, landbouwkundig, milieukundig) pasten in het *People-Planet-Profit* raamwerk en verschilden in ruimtelijke schaal, tijdschaal en eigenaarschap. Vanuit een boerenperspectief redenerend bleek de afwezigheid van significante verschillen in respons tussen aanbevolen en huidige boerenpraktijk opvallend; bij het innemen van een meer landbouwkundig perspectief leken lage fosfaatniveaus in de bodem respons op de aanbevolen kunstmestgift te beperken. Gelijktijdig werd duidelijk dat duurzaamheid in de vorm van evenwichtige nutriëntenbalansen op perceelschaal moeilijk te bereiken was; enkel door gebruik van aanzienlijke hoeveelheden organische mest en ten koste van de graanopbrengst zou dit bereikt kunnen worden. Redenerend vanuit een milieukundig lange termijn perspectief bleek het traditionele landbouwsysteem verassend duurzaam door de combinatie van een gemengd landbouwsysteem met relatief lage opbrengsten. We concludeerden verder dat, afhankelijk van het ingenomen perspectief, verschillende interventies konden worden voorgesteld. Het combineren van de drie perspectieven gaf aan dat het geleidelijk versterken van het bestaande gemengde bedrijfssysteem door het gebruik van kunstmest, organische mest en braak met vlinderbloemigen, uiteenlopende aspecten van duurzaamheid kan ondersteunen in de vorm van hogere gewasopbrengsten, hogere voedselzekerheid en meer rendement. In lijn hiermee suggereerde de gepresenteerde analyse van verschillende gezichtspunten, dat in ons studiegebied voor boeren voornamelijk transities met een laag risico relevant zijn en dat deze expliciet meegenomen moeten worden bij de ontwikkeling van transitietrajecten. In processen waar stakeholders met verschillende gezichtspunten samenwerken is het belangrijk om de verschillen ertussen te kennen en gebruik te maken van de mogelijkheden om meerdere perspectieven te betrekken en integreren in analyses.

Participatief onderzoek waarin boeren en onderzoekers betrokken zijn vaak gebaseerd op processen van experimenteel leren en hieraan gerelateerde verandering. Deze processen van leren en verandering waren essentieel in de context van ons onderzoeksproject maar zijn over het algemeen moeilijk te duiden. In hoofdstuk 7 beschouwden we door ons waargenomen en door de boeren gerapporteerde veranderingen in relatie tot functionele en *human-social* aspecten welke mogelijk het gevolg waren van betrokkenheid bij participatief onderzoek. *Inputs* van onze kant werden opzettelijk geminimaliseerd om maximale controle over het proces door de boeren te garanderen en bias door het geven van materiële *incentives* te voorkomen. Gebruikmakend van data gebaseerd op interviews en andere observaties hebben we vastgesteld welke veranderingen hebben plaatsgevonden en in hoeverre deze het gevolg waren van betrokkenheid bij het participatieve onderzoek. Tevens leverden interviews en observaties meer inzicht in het participatieve proces op. Boeren gaven aan dat ze meer kennis hadden en zelfvertrouwen in het toepassen van bepaalde agrarische praktijken zoals bijvoorbeeld een exactere dosering bij het gebruik van kunstmest. Ze raakten ook meer vertrouwd met systematisch experimenteren en bereikten in de meeste gevallen een redelijke respons. We vonden ook dat deelnemende boeren verschillend van de eveneens geïnterviewde controle groep: zij zouden niet-familieleden meer betrekken in discussies over bedrijfsmanagement en *officials* eerder benaderen om problemen in de buurt op te lossen; verder zouden zij meer met landbouwvoorlichters discussiëren over bedrijfsmanagement en waren ze specifieker in hun ambitie over landbouw te leren. Positieve veranderingen ten aanzien van gewasopbrengst en armoede werden verder door deelnemers meer genoemd dan door de controle groep. Deelnemende boeren beschouwden hun betrokkenheid over het algemeen als waardevol en gaven het leren als meest gewaardeerde aspect van deze betrokkenheid aan. Alle 16 groepen bleven betrokken gedurende de vierjarige looptijd van het project en gaven tevens aan op eigen kracht verder te willen gaan. Het evalueren van een set van factoren welke betrokkenheid mogelijk ondersteunden leverde enkel het bereiken van een redelijke respons als factor op welke over alle groepen belangrijk was. Alle andere factoren waren zeer variabel verdeeld over de groepen en leken eerder *trade-offs* te zijn dan *knock-out* factoren. Bij het ontwerpen van participatieve onderzoeksprocessen is het daarom belangrijk aandacht te besteden aan dergelijke samenhangende, maar ook diffuse sets van factoren. Gegeven de diversiteit van de groepen is het verder niet waarschijnlijk dat het volgen van een blauwdrukmethode de variatie tussen verschillende groepen voldoende recht zal doen.

Op basis van de bij elkaar gevoegde stukjes concludeerden we dat participatief onderzoek op verschillende manieren bijdroeg aan veranderingen bij de betrokken boeren op zowel functioneel als *human-social* vlak. Dergelijke bijdragen relateerden, onder andere, aan zelfvertrouwen, landbouwkundige praktijk, opbrengsten en omvatte verschillende zogenaamde *livelihood capitals*. Onze betrokkenheid in het onderzoeksproject leidde tot een beter begrijpen van participatieve onderzoeksprocessen en de complexiteit van het landbouwsysteem. Belangrijke inzichten relateerden aan de impact van keuzes gemaakt in de loop van het proces, mogelijke bronnen van motivatie en de verdeling van verantwoordelijkheden. De diversiteit van de groepen vereiste een groep-specifieke benadering en een open proces waarbij de groep en haar functioneren centraal staan.

Participatief onderzoek kan rurale transitie processen in Tigray ondersteunen. Belangrijke aspecten hierbij zijn de mogelijkheid om context-specifieke uitkomsten te genereren en de bijdrage aan functioneel en *human-social* gerelateerde verandering van de betrokken boeren. Belangrijke punten om dit te bereiken zijn: delegeren van verantwoordelijkheden naar de boeren in alle fasen van het proces; een adequate facilitering van het proces; het inbedden van participatief onderzoek in bestaand organisaties en instituties; het werken op lage schaalniveaus om inbedding in de lokale gemeenschap en relevante mogelijkheden voor opschalen veilig te stellen. Participatief onderzoek heeft in de context van Tigray onomstotelijk potentie om als *change-agent* transities naar duurzamere mogelijkheden van bestaan in gang te zetten.

Acknowledgements

The start was the idea: - *Would it be not great if farmers, in this case in Ethiopia, could work on their development by themselves and in this way make progress* –

That farmers know about their environment and what works and what does not work was not new for me, and in Ethiopia, during my stay at Mekelle University, I became acquainted with and very enthusiastic about working in a participatory way with farmer groups. To me farmers experimenting together with researchers would clearly lead to solutions for the (agronomic) problems farmers were facing. But at the other side there were also reservations and to mention some is not difficult: do the farmers involved have sufficient knowledge about novel technology; can they interpret the experiments conducted; can they manage their own learning; how can it be scaled.

Having this in mind, I realized that only a long-term research project could shed light on questions about the effectiveness of such approaches. At a certain moment, during an excursion in France, Tom Veldkamp, my promotor, asked me - why not doing a PhD with him - and I realized that this was probably the only way to work on such questions. This invitation was the start of a long period of co-operating and I want to thank Tom for always being there when needed, sometimes at a distance, sometimes in close co-operation when brainstorming about a paper; most of all I want to thank you, however, for unconditionally believing in the project and in me in difficult times. Not only in dealing with financial constraints; with issues about the continuation of the project; with critical reviewers; but also in giving hands in harvesting manually together with farmers and our MSc-students (Henrieke and Susanne) somewhere on a small field in Hagere Selam with ancient agricultural flintstone artefacts!: an experience I never will forget.

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challenging for both of us: you were always critical on the structure (*are the questions answered?*), the terms used (*these are not interviews!*), and often used the perspective of an external reader (*explain, explain, explain …….*); I had in mind where I wanted to go to but mostly did not know the way and was not always easy to convince. Your assumption was often that we were very different in thinking, but I can assure you we were much more on the same line than you presumed. I also want to thank Cees for supporting this PhD-project as a promotor in its final phase; I hope you consider it a good contribution to the work of your group.

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Although we stayed quite some time together in Ethiopia, I was also absent from my family for some months. Writing this thesis also meant spending less time with Twedros, Yohannis and Dhani; I want to apologize for that and I hope to be much more their father from now on. From all my heart I want to thank Hidat, not only for her enormous and unconditional help in conducting interviews and workshops; strolling together through the fields of Tigray; asking again and again the way to *Ato* X; our shared believe in farmers' ability to deal with their problems; but even more than that for taking care of us and for giving that crazy little something ruling us: love.

Looking back, I guess that working in the fields with the farmer groups sometimes was hard, but at the same time it always felt so light just to be there and being so very, very far from NDS (normalized dutch stress level) brought tiny flickers of happiness, enough to make my job easy. To end with the start: to do a PhD needs an idea to work on, but at the same time a drive to keep on working and stay inspired: Thanks to all who kindly reminded me to stand with those who stand aside.

PE&RC Training and Education Statement

With the training and education activities listed below the PhD candidate has complied with the requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities)

Review of literature (4.5 ECTS)
- Developing site specific approaches to improve productivity under low external input conditions

Post-graduate courses (7.5 ECTS)
- Photosynthesis, climate and change; PE&RC (2013)
- Plant nutrients in terrestrial ecosystems; PE&RC (2014)
- The art of crop modelling; PE&RC (2013)

Invited review of (unpublished) journal manuscript (1 ECTS)
- Agriculture, Ecosystems and Environment: livelihood development (2014)

Deficiency, refresh, brush-up courses (1.5 ECTS)
- Basic statistics (2009)

Competence strengthening / skills courses (2.4 ECTS)
- Curriculum development natural resource economics and management; MU-LIAC project; Mekelle University (2003)
- Workshop institutional university cooperation partnership VLIR-Mekelle University; VLIR-UOS (2003)
- Curriculum development workshop; Mekelle University (2009)
- Education development days; Van Hall Larenstein, University of Applied Sciences (2014)

PE&RC Annual meetings, seminars and the PE&RC weekend (1.2 ECTS)
- PE&RC Weekend (2008)
- Sustainable agriculture: intensification of ecologization (2013)

Discussion groups / local seminars / other scientific meetings (5.3 ECTS)
- Future of land evaluation (2007)
- Farming futures in SSA (2008)
- Discussions with staff at Mekelle University (2008-2014)
- Photosynthesis (2009)
- Global soil fertility (2011)
- Caritas Tigray (2011)
- The second law in Earth System Science (2012)
- Climate change and smallholder farming in SSA: what role for adaptation (2014)

International symposia, workshops and conferences (9 ECTS)
- Water; Mekelle University, Ethiopia (2011)
- Livelihoods; Mekelle University, Ethiopia (2013)
- Global Food security; presentation; Noordwijkerhout (2013)
- N; presentation; Kampala, Uganda (2013)
- EGU; presentation; Wenen (2014)

Supervision of MSc students (6 ECTS)
- Soil management
- Digital soil mapping