Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

Transdisciplinary Research: Collaborative Leadership and empowerment towards the Sustainability of Push-pull Technology

Nyangau I.M.[1,2], Kelboro, G.[1], Hornidge, Anna-K.[3], Midega C.A.[2] and Borgemeister, C.[1]

[1]Center for Development Research (ZEF), University of Bonn, Genscherallee 3, Bonn, Germany
[2]International Centre of Insect Physiology and Ecology (ICIPE), P.O. Box 30772- 00100, Nairobi, Kenya
[3]Leibniz Center for Tropical Marine Ecology (ZMT), Bremen University, Fahrenheitstr 6, Bremen, Germany

Abstract

Transdisciplinary research approach requires that different scientists with their discipline-specific theories, concepts and methods find ways to work together with other societal players to solve a real-life problem. In order to put this into practice, Trans-disciplinary Action Research (TDR) approach was applied in this study using Push pull technology (PPT) as a boundary object. The study was conducted in Bako Tibe, Jimma arjo and Yayu *Woredas* (Districts) in the Oromia region of Ethiopia from August 2014 to April 2015. PPT is a biological based mechanism developed by researchers for stemborer pest control in maize. It involves inter-cropping maize with a stemborer moth-repellent silverleaf or Greenleaf Desmodium (push), and planting an attractive trap crop, Napier or Brachiaria grass (pull), around the maize crop. On farm PPT implementation was used to provide an opportunity for collaboration, interaction and learning among heterogeneous set of stakeholders comprising of researchers from Ethiopian Institute of Agricultural research and the practitioners from the ministry of agriculture and smallholder farmers/traders. The data was collected using mixed methods approach comprising of key informant interviews, Focus Group discussions, workshops, on-farm practical demonstrations and participant observations. The findings shows that; collaborative leadership provides a chance for the stakeholders to participate in the technology learning and decision making by enabling them to jointly contribute skills towards development, refinement and adaptation of PPT. In situations where there are conflicts, they are embraced and become opportunities for in-depth learning, finding solutions and adaptation rather than being sources of contradictions or misunderstandings. Leadership roles taken by farmers play a key role in terms of ability to reflect on their own practices and drawing on scientific explanations from researchers. It also enables them take lead in new technology implementation and information sharing in free and easy manner with fellow farmers and other stakeholders. Although PPT perennial nature of cropping provides opportunities for continuous stakeholder interaction and learning, it requires a personally committed leadership and formal institutional engagements for the sustainability of its activities spanning over several cropping seasons. Market forces and the involvement of private sector players also has a role to achieve this as shown from the involvement of individual farmers and traders in Desmodium and Brachiaria seed production, collection and distribution.

Key words: Collaboration, leadership, Push-pull technology, sustainability, transdisciplinary research, Ethiopia

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2018 doi:10.20944/preprints201804.0062.v1

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

1.0 Introduction

The uptake of academic research into policy and practice requires the input and active participation of other societal stakeholders. In transdisciplinary research, the non-academic or lay persons participation bring multiple knowledge and expertise which is vital to the research process where it is framed and conducted with flexibility (Bracken et al., 2015). Indeed, it is almost impossible to ignore transdisciplinarity when engaging in sustainability research and vice versa. This is because; these approaches are aimed at solving the society's challenges. The challenges require new ways of knowledge generation and decision making from the involvement of the diverse stakeholders including those from outside academia (Lang et al., 2012). The process is promising when these approaches have clear set out goals and competent management to facilitate creativity, innovation and manage conflicts which may exist or arise out of the stakeholder engagement (Wright et al., 2015). The Participation of non-academics is in fact democratizing the research process and is meant to produce better and socially robust research outputs (Hirsch Hardorn et al., 2008; Hoppe, 2005; Lang et al., 2012; Nowotny et al., 2004; Stauffacher et al., 2008). The heterogeneous nature of participants and their contributions add meaning on the research agenda and to decision making. Thus, making the knowledge production a democratized process to such an extent that, the dominant and non-dominant actors have equal access and ability to contribute towards solving societal problems (Bunders-Aelen, et al., 2010). According to Popa, et al (2015), transdisciplinary research, aims at establishing a form of collaboration which empowers stakeholders to influence the research, to question and to modify the dominant structures which guide epistemic processes. In other words, the process enhances mutual learning for knowledge production between researchers and other stakeholders, and to bring about empowerment of the participants either through education on areas of interest or to have their agenda and perspectives integrated in the knowledge production process (Siebenhüner, 2004). Authentic and inclusive participation empowers the stakeholders to become better agents of change in their community from problem identification to implementation (Mobjörk & Centrum för urbana och regionala studier, 2009; Mobjörk, 2010). This model of research in sustainability science has embraced a sequence of stakeholder engagement and involvement from that of informing to consulting to collaborating and to empowerment where practitioners are given authority to implement the research findings (Harris & Lyon, 2014; Reid et al., 2016). In this case, empowerment is seen as a process of providing stakeholder with the power to make decisions right from research planning to the use of the findings. Such kind of empowerment is bound to take place when is linked with leadership and innovation (Schäpke, et al., 2017).

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

Transdisciplinary leadership comes in handy when mediating stakeholder engagement and interaction for fruitful collaborations at the level of boundary-crossing (Crosby & Bryson, 2005; Bushe, 2009). Although the diverse sets of stakeholders are brought together by a common societal problem, they are still ascribed to different disciplinary, organizational and institutional silos (Gray, 2008). In order to overcome these boundaries, a collaborative leadership plays an important role (Archer & Cameron, 2009; Chrislip, 2002; Frydman et al., 2000). According to Linden (2002), collaborative leadership is required when people from different agencies or agency units work together in a common project to address a common problem. To make progress in tackling the common problems, all these stakeholders must take on the leadership challenge of building shared-power arrangements (Crosby & Bryson, 2005; Harris & Lyon, 2014). What stands out about such empowerment and active leadership is that, it is not motivated by personal power needs, but the potential through which such stakeholder collaboration can be used to address a common societal problem for mutual benefits, and such leaders are passionate on bringing results to fruition (Pedrosa, 2009). A collaborative leader therefore, has a responsibility to provide guidance, coordinate the transdisciplinary research process and ensure that, the other stakeholder groups participate in making decisions and taking actions in a democratic atmosphere to address the problem at hand. As stated by Gray (2008), such a leader is equated with a transformative leader who has ability to combine cognitive, structural, and processual tasks:

> "The task of effective cognitive leadership is to provide a vision and commitment that links and motivates the scientific researchers to step beyond their disciplinary silos, relax old assumptions, and search for creative frame-breaking solutions…. Effective structural leadership adds value by breaking the gaps existing between science and practice through building bridges… Effective processual leadership task encourages trust and turns potentially destructive conflict into constructive and participatory interactions" (Gray, 2008, pp. 9).

Leaders with collaborative management skills may make a difference between success and failure in transdisciplinary efforts from their charismatic personality, knowledge base, broad network and engagement (EU SCAR, 2012), but they shouldn't be static in their engagements with their stakeholders. According to Wright et al. (2015), such leaders should have the ability to anticipate challenges during the transdisciplinary process, learn from failures in case they happen, and be flexible in the process and adapt to new conditions within the overarching objective of addressing the problem at hand. Under this study, stakeholder interactions and engagements during PPT implementation required such kind of collaborative approach and leadership. This is because, the whole process of implementation encompasses stakeholder interaction and in depth learning and reflection on PPT workings and related enterprises or activities.

Such innovative processes on joint innovation implementation require leadership with strong advocacy at scientific research and practice levels and, at the same time, willingness to play a central role in the promotion of a free and divergent thinking, risk taking, and readiness to challenge the established methods, theories and practices (Henriksen, 2011). Thus, the study was aimed to explore how PPT can be effectively used as a boundary object in a transdisciplinary research process to strengthen such collaborative leadership and the empowerment of different actors across science-practice boundaries engaged in stemborer pest control. Researchers, extension workers and farmers jointly worked together during all the critical stages of PPT implementation from planning workshops to farm establishment, management and evaluation stages. Collaboration among the stakeholders was instrumental to ensure that their engagement and interaction worked in terms of learning and effective PPT implementation. This paper highlights how during PPT implementation, the collaborative leadership was enhanced among the stakeholders especially the smallholder farmers and contributed to empowerment, creation of new linkages and relationships for the sustainability of PPT.

1.1 Definition of Key Terms.

Agricultural Innovation: Refers to the "development or adoption of new agricultural technologies, concepts or ideas, and/or successful exploitation of new ideas. It also embraces the totality and interaction of actors involved in the development of the ideas" (World Bank, 2006: p, vii).

Boundary objects:

> "These are objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. […]. This is an analytical concept of those scientific objects which both inhabit several intersecting social worlds and satisfy the informational requirements of each of them" (Star &Griesemer, 1989: p, 393).

Transdisciplinary Research (TDR): Researchers and other societal players work together by integrating their knowledge and perspectives into a shared problem definition (Rosenfield, 1992; Ul-Hassan *et al.,* 2011) to solve a real life problem. In this study, TDR is operationalized to refer to joint efforts of research scientists consisting of entomologists, chemical ecologists, weed scientists, social scientists, and other stakeholders consisting of farmers, traders, extension service providers (public or private sectors), input suppliers, NGOs, community based organizations and farmer groups/associations working together in PPT implementation.

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

Push-Pull Technology: Refers to a cropping strategy for controlling stemborer pests and *Striga* weed in maize where it is intercropped with a stemborer moth repellent fodder legume, Desmodium (the push) with an attractant trap plant, such as Napier grass (the pull) planted around this intercrop (Chamberlain et *al.* 2006). In this study PPT is operationalized as a boundary object.

Stakeholders: Refers to a person, a group or organization who have interest or concern and are affected by the innovation or their activities strongly affect the performance of the innovation (Ul-Hassan *et al.,* 2011). In this study stakeholders include; Researchers, farmers, traders, extension service providers (public or private sectors), input suppliers, NGOs, community based organizations and farmer groups or associations.

1.2 How PPT Works

Push-Pull Technology (PPT) strategy is a multi-functional innovation platform that addresses concurrently cereal production constraints of stemborers, *Striga* weed, low soil fertility and low soil moisture retention. In the strategy maize is intercropped with a stemborer moth repellent fodder legume, Desmodium (the push), together with an attractant trap plant, Napier/Brachiaria grass (the pull), planted around maize-legume intercrop (Fig. 1). The green leaf volatiles produced by Desmodium repel stemborer moths while those produced by the trap grasses attract them (Chamberlain *et al.,* 2006). In addition, Napier grass or Brachiaria grass does not support all stemborer larvae to develop and hence the majority of them die before reaching adulthood (Khan *et al*., 2007). Besides stemborer control, Desmodium also suppresses and eliminates *Striga,* leading to significantly enhanced maize grain yields (Khan *et al.,* 2006). Studies have identified the mechanisms by which Desmodium suppresses *Striga,* with an allelopathic effect being the most important one (Tsanuo, *et al.,* 2003). Desmodium roots produce a blend of chemical compounds, some of which stimulate *Striga* seeds to germinate while others inhibit lateral growth of *Striga* roots, thereby hindering their attachment to maize roots, i.e. suicidal germination (Khan *et al.,* 2000; 2002; Tsanuo *et al.,* 2003). *Striga* emergence is thus suppressed, with an *in situ* reduction of soil seed bank (Khan *et al.,* 2002). In addition, PPT supports; crop-livestock integration through fodder provision, soil improvement, agro-ecosystems resilience through crop intensification, income generation and meeting food security demands of smallholder farmers (Khan*, et al.,* 2008). Currently over about 100,000 farmers are practicing PPT in East Africa (Khan *et al.,* 2014). However, this number of farmers is still low compared to the intensity and magnitude of the biophysical constraints and the population of smallholder farmers in the east African region whose livelihood could potentially be improved with the implementation of PPT. In addition to addressing the problem of pests, in this study

PPT serves as a platform upon which scientists and stakeholders can come together to learn, integrate their different perspectives, and complement each other, resulting in the generation of new practices and knowledge meant to solve real-life problems.

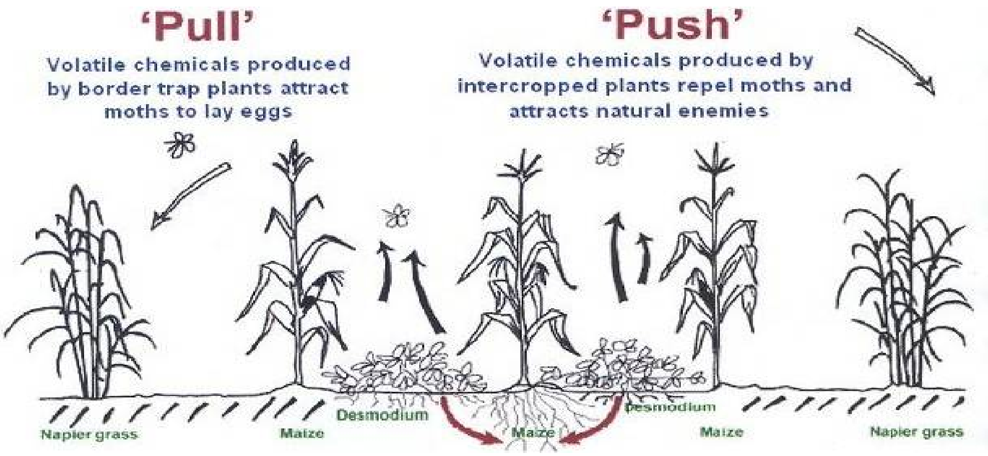

Figure 1. How Push Pull Technology works

Source: www.push-pull.net

2.0 Methodology: Transdisciplinary Action Research process

The implementation of the study was based on transdisciplinary action research (TDR) process (Siarta *et al.,* 2012) and drawing on the experiences of the *Follow the Innovation* (FTI) approach which was developed by the Center for Development Research [ZEF] in the context of Uzbekistan's agriculture (Hornidge *et al.*, 2009; Ul-Hassan, 2011; Hornidge *et al*., 2011). Action research design is an interactive, collaborative and rigorous iterative process which engages practitioners in managing systematic enquiries to improve their practices and better realize their desired outcomes and contribute effectively towards the longer term goals (Allen *et al.,* 2014; Kohler, *et al*., 2011). It is a systematic (Fig. 2) and participatory paradigm that supports transdisciplinary reflective learning, communication and co-operation between the different stakeholders in the learning and knowledge production for addressing the real-life problems, developing innovative solutions and incorporating them in new action strategies (Bortz & Döring, 2003; Siarta *et al.,* 2012).

As a joint process, the transdisciplinary action research was used as a strategy to enable learning among researchers and other stakeholders, to share their knowledge and experiences towards the production of locally adaptable knowledge (Miller *et al*., 2008, cit. in Dessalegn, 2013) in this case, the control of stemborer pests in maize. The team of researchers consisted of an entomologist, chemical ecologist, weed

 doi:10.20944/preprints201804.0062.v1

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

scientist, social scientist whereas other stakeholders included farmers, agro-dealers, public extension service providers and smallholder farmers. TDR is premised on good communication between researchers and other stakeholders to ensure that knowledge sharing and learning takes place with eventual empowerment and development of new knowledge or practices. PPT implementation followed maize crop agronomic and management practices spanning from before and after harvesting. This included but not limited to land preparation, planting, weeding, harvesting of either as green maize cobs for roasting or dry cobs for cereals, harvesting Desmodium and Brachiaria grass for fodder for livestock and seeds. After harvesting maize, the process involved off-cropping season activities mainly on the process evaluation of the learning outcomes and impacts.

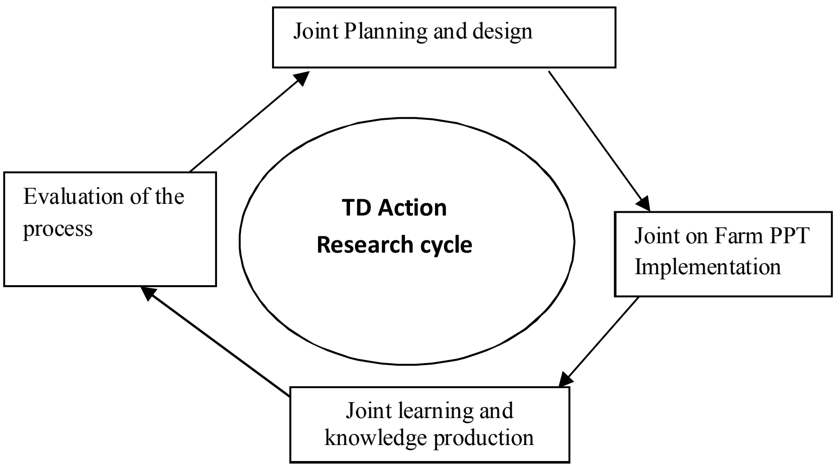

Figure 2. Transdisciplinary Action Research Cycle

Source: This study

2.1 Data collection methods

The data collection process was using qualitative methods. The process engaged 37 key informant interviews (KI), 16 Focus Group discussions (FGD), 2 stakeholders' workshops, on-farm practical demonstration and participant observations (PO). The study lasted 8 months from August 2014 to April 2015. The KI interviewees were mainly researchers, extension and administration officers from the ministries and farmer leaders. The FGD participants were PPT farmers and their neighbors. The PO were based the researcher's observation during on-farm practical demonstrations and workshop discussions to

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

document observations on the attitudes, behaviors and actions of the participants. The data collected was on: the background information on stemborer pest's problem; the past experiences on stemborers pest problem in cereal crops mainly maize and sorghum and effect on yields, type of control measures they were applying and the effectiveness, alternative control measures so far used, how PPT management practices were different from usual practices, new opportunities, practices and knowledge gained and challenges faced and the suggestions on what; is required to be improved to make PPT more effective, incentives to be in place for sustainability and attract other players to participate in PPT implementation.

2.2 The Study Area

The study was implemented in three *Woredas* in Oromia Region in Western Ethiopia, namely Bako Tibe, Jimma arjo and Yayu (Fig. 3). These sites were identified in Ethiopia using a GIS based 'hot-spot' approach by African and German partners of the BiomassWeb project[1]. The *Woredas* are located in the western parts of Oromia and were selected as the potential 'maize growing basket' of Ethiopia (Abate et al., 2015; Abdissa et al., 2001) in which the "livelihood of local communities […] traditionally stands on household-based subsistence agriculture, extensive use of forests and cultivation on considerably small plots of agricultural land with an average of one hectare of cropland mainly for the cultivation of staple cereals such as maize, *teff* and wheat" (Stellmacher and Grote, 2011: P, 10). The soils in the areas are either severely degraded due to nutrient depletion, and/or poor in organic matter from continuous mono-cropping and unsustainable farming practices. Insect pests, principally stemborers, are major cereal production constraints (Assefa, 1998; Belay & Foster, 2010; Getu et al., 2001). According to Hurni (1998), the area is characterized mainly by mono-modal rainfall, with short rains in March and April, and long rains from June-October, with a distinct dry season extending usually from November to February. The dominant soil types are Nitosols with fertile alluvial soils in valley bottoms and depressions. Major crops, in order of importance, are maize, *teff*, pepper, sorghum, millet and pulses. In Yayu, coffee is an important cash crop. The farming system is mixed crop-livestock based.

[1] http://www.zef.de/2141.html

Table 1: Study area and location of the PPT demonstration plots

Study area and Location of the PPT demonstration plots							
Zone	*Woreda*	*Kebele*	AEZ	Location of the plots	Altitude	Longitude (N)	Latitude (E)
West Shawa	Bako Tibe	Dembi Gobu	Mid-land	Gibe river	1660	09°09.173'	037°02.131'
		Seden Kite	Mid-land	Leku river	1648	09°05.331'	037°09.847'
East Wollega	Jima Arjo	Wayu Kumba	High land	Nageso river	1990	08°46.442'	036°31.616'
		Wayu Kumba	High land	Nageso river	1986	08°46.582'	036°32.554'
Ilu-Ababora	Yayu	Jame Shono	High land	Sky-sky	1904	08°21.353'	035°36.584'
		Jame Shono	High land	Jame-Bone	1870	08°21.351'	035°57.736'

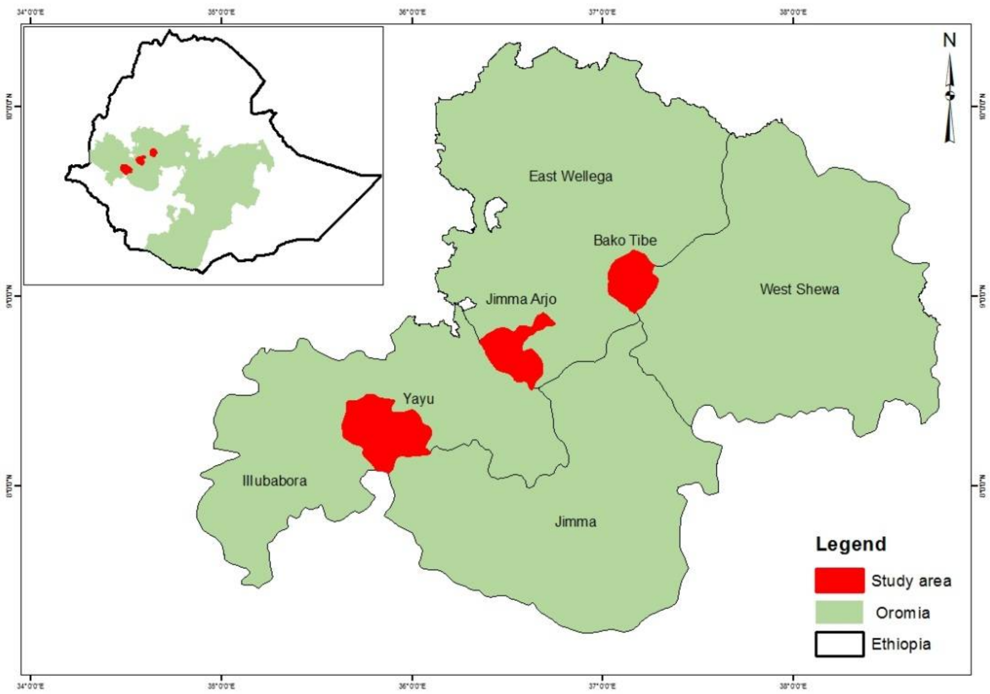

Figure 3. Map of the study area in Western Oromia, Ethiopia

Source: ZEF GIS expert

3.0 Discussion of findings

3.1 Transdisciplinary Action Research: An opportunity for empowerment and to nurture farmers' leadership

The PPT implementation process was undertaken based on a joint and collaborative environments from workshops to on-farm discussions and activities, where the researchers and other stakeholders interacted, contributed and applied their knowledge and practices on how PPT activities could be undertaken to address the problem of stemborer pests and other challenges such as fodder for livestock, soil and water conservation. During the processes, the researchers' contributions were based on their scientific knowledge mainly from laboratory and on station research experiments while the farmers and extension staff contributions were based on their experiential and on the day to day encounters with these problems at farm level. In the conventional research-extension-farmers linkages, the farmers are regarded as mere recipients of the already tested and ready to use knowledge or practices. In the joint stakeholder implementation of PPT, it was a different approach to overcome such boundaries which exists between research and practice whereby the farmer stakeholders are empowered and have a role to play in bridging the gap between research and practice and to make the linkage stronger and more effective.

Previously, efforts have been made to break research-practice gaps through the introduction of new technologies in Ethiopia (Deneke and Gulti, 2016). But in a situation where there are different levels of participation and the farmers are the recipients of technologies and the research and extension organizations are controlling resources for implementation, it is not easy to eliminate the gap (Wenger et al 2002; Deneke and Gulti, 2016). Such type of relationship with the farmers has tuned and conditioned them with the belief, whenever new technologies are introduced; their level of participation is limited to following and adhering to instructions from researchers and extension staff (Wenger et al., 2002). However, this study the initiative of transdisciplinary research approach was seen as an opportunity for empowerment through bestowing confidence in the farmers and making their views, knowledge and skills shared with researchers and extension staff on an equal basis. The new skills learnt and knowledge generated from such interactions was meant to inform further research and practice. Although it takes time for such initiatives to become fully entrenched in the way of conducting research and extension activities, the good intention was to initiate and nature such sort of leadership amongst the farmers.

In Ethiopia, the extension staff tends to serve as agents of centralized political power in their respective *Woredas* or *Kebeles*. In the course of their work, they are mostly engaged in delivering political messages

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

and undertaking tasks on behalf of the ruling party such collecting taxes under the cover of extension work (Berhanu & Poulton, 2014). Under such circumstances, the farmers lose trust whenever new initiatives are introduced by the same people who they suspect to have an underhand for the 'state authorities'. However, in a situation where there are efforts to build the trust and confidence, the farmers are able to take the initiative seriously and even to a step further. For example, the sustainability of PPT is not only dependent on its performance, but on market forces from supply and availability of seed inputs. In addition, it is depended on leadership initiatives from micro level i.e. at the household level where the head ensures that all members of the household participate and are empowered with PPT based skills. The farmer is able to organize and allocate his farm family in terms of labor and responsibilities on PPT activities. In this case, PPT is implemented as an enterprise where the different family members are empowered to exploit the various benefits and opportunities which come with the technology e.g. from seed production, fodder production for livestock fattening, milk production and marketing. This is also in anticipation that one of the family members is incapacitated or moves on to other activities, the rest of the family members are able to continue with the technology implementation.

This sort of leadership at family level is built from the confidence and empowerment made on the farmers whereby their role is recognized by both research and extension professionals. The farmers' leadership was demonstrated by their ability to initiate, conduct experiments and take decisions freely regarding the PPT implementation. For example, researchers recommend the establishment of PPT using line planting where the seeds are sown in holes or drills using a straight line. However, the farmers in the study sites preferred to use ox-drawn ploughs to drill the lines (Fig. 4). These lines may not be straight as required or recommended by the research or extension, but the farmers in a participatory and democratic learning process; they were able to make decisions and had valid reasons on what works best for them. This was different from previous relationships where they were dictated by the DAs or local administration and researchers on what to do during on-farm trials. This time round, they were able to use own measurements and tools:

> "The joint implementation of PPT enhances participatory leadership in its approach whereby it enables everybody from farmers to researchers to participate in the technology. Thus enabling all the participants (i.e. stakeholders) to develop and contribute skills to manage its implementation and also push the research agenda… Through this approach new players are attracted into the research process and contribute to good results e.g. the private sector, youths and women….all the players involved are able to learn new skills on PPT openly from each other and by drawing on own experiences" (*KI Bako researcher, April 2015, Bako research center)*.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2018 doi:10.20944/preprints201804.0062.v1

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

Figure 4. Pictures of farmers, extension officers and researchers joint sessions of establishing PPT

Source: This study

The effort to change research and extension services provision is in line to what has been recommended by Deneke and Gulti (2016) that, linear relation should be replaced by systems which are iterative, interlinked and also overlapping where by the role of the farmers is not that of recipients of technologies developed elsewhere but to empower them to have confidence and trust in order to contribute to decision making together with other stakeholders. The Stakeholder collaboration process was organized in such a way that, the on-farm implementation process was undertaken in a participatory manner by the team consisting of the farmers, grassroots extension personnel (DAs and district level extension) and researchers. The on-farm PPT activities created a platform for these stakeholder groups to interact and learn various topics related to stemborer pest control, soil and water conservation and fodder production. Such joint working relationship was an opportunity for each stakeholder to introduce and contribute skills on the management and implementation of PPT and other related emergent enterprises or benefits:

> "The DAs, researchers, visitors from overseas, Germany and Kenya, have been with us from the start to date… Team work always has positive outcomes…. The team has been around from sensitization, training, planning for all the implementation stages to now…This has formed a continuous interaction process for learning and appreciating the efforts of each other")*Comment Development Agent, Bako Tibe, March 2014).*

The farmers had confidence with the promoters of the technology. This was based on the reputation of PPT which they heard; it has been researched vastly and there were a lot of experiences to draw from other countries in the eastern African region such as Kenya, Uganda and Tanzania. They share similar circumstances with farmers from these countries who are also faced same stemborer challenges. They were flexible and at ease to make decisions about the PPT from the beginning. In their own circumstances

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

as Ethiopian farmers, 2-3 cropping seasons with PPT, is when they shall have had own concrete experiences. At the moment, they were optimistic:

> *"icipe* Director General is Ethiopian and she is supporting this technology…. She is fully aware of its benefits, so we shall fully embrace it and make it a model. What she thought for her country and population to come out of poverty and challenge of being faced with pests, erosion, and fodder. We are receiving this information through the extension and researchers at the local level" (*PPT farmer, Bako Tibe, April 2014).*

In addition to cereal crops, farmers grow horticultural crops for household consumption and for the local market as a source of cash income. These crops have similar pest problems such as nematodes, armyworms, Aphids etc. Out of curiosity to find a solution to the horticultural pest problem as well, a farmer raised a question whether Desmodium could help in addressing the problem on tomatoes and cabbages on his farm. This was an interesting question for the researchers and extension alike. The farmer took the initiative to raise the question because; he observed for the first time, that the maize crops had less infestation of with stemborer pests when compared to the previous seasons. Parallel to the question, instead of waiting for an answer from researchers, he offered to run the trial experimentation by growing tomatoes on 25m by 25m plot intercropped with Desmodium. Out of this plot, he planned to take records and make observations which he could share with researchers and extension staff. Such a gesture from the farmer could be attributed to empowerment, confidence and freeness gained from the joint nature of interaction with researchers and the extension staff. This also was a boost to the farmers to believe that their ideas and simple experiments can make a contribution towards generating new knowledge in a research process. Such experimental test is an example of how empowering and enhancing farmer's confidence to engage researchers and also raise research questions and to challenge existing methodology could contribute to generation of new knowledge in pest control. The farmers experimentation combined with the laboratory based methods can potentially reduce the time taken to generate results or waiting time to address their immediate needs or real life problems.

Weeds compete with the maize crops for nutrients and moisture. It is assumed that the farmers should free their maize off weeds even when the crops have matured. However, the farmers had a different perspective. At the later stages of maize growth when they start flowering or forming grains, the farmers stopped weeding. From their point of view, the weeds together with maize stalk leftovers were to be used as fodder for livestock after harvesting the maize cobs. At the same time, weeds retain soil moisture due to sufficient soil cover. With the introduction of PPT, some farmers in the area saw similarity with weed retention. They were able to connect with what they already knew and what the PPT had in store for

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

them. Instead of previously leaving weeds to grow with their crops, the introducing Desmodium was a novel idea. It address the stemborer problem and as an additional source of fodder. This helped to dispel the rumors which were initially spreading in the study areas that Desmodium was a weed being introduced by researchers and extension staff. However, only a few farmers could see or overcome the rumored messages. The group of farmers who went ahead to implement PPT despite the rumors became the lead farmers and eventually they are seen as leaders to their community. They embrace leadership role for fellow farmers to emulate. They are also able to make decisions based on their experiences and what they think is of best interest to their community.

> '…..the overgrown weeds are fodder for livestock. Immediately after the harvest of maize, animals are left to freely loam and feed on "weeds" plus the maize stovers. …Now with PPT, Desmodium does the same. Besides, it is a perennial crop which can be cut back and fed to livestock. It is a permanent source of fodder ….. this is good" (*PPT farmer, during FGD interviews, March 2014).*

The concept of intercropping Desmodium with maize and as effective cover crop did not flow smoothly as one would have thought or expected. Some of the farmers were reluctant to embrace the PPT either due to cultural orientation or personal attributes such as fears or not trusting new information or technologies or being swayed by rumored information. For example in Yayu *Woreda* some farmers were thinking that Desmodium was weed and wild plant being introduced into their farms to bring unnecessary competition with food crops or to be just a nuisance. According to some of these farmers, Desmodium was annoying. It gets stuck on cloths when walking through or weeding their maize fields. Some of them knew Desmodium as a wild plant growing on the farm hedges or in the forest and couldn't comprehend the fact that it can be an intercrop with maize. At the same time, freely roaming of grazing livestock is a common practice in the area after harvesting maize. Therefore, to some of these farmers and some of the researchers and extension staff, the introduction of PPT was not likely to work. In particular, this was because, immediately after harvesting, livestock are released to roam freely through their farms. This potentially will destroy the perennial PPT companion crops. However, such doubts were expected because PPT was being introduced into the area for the first time. The emergence of negative rumors, lack of prior and correct information are some of the key areas concern which had to be understood and addressed from the beginning of the implementation process to allay any further fears on the technology. However, these issues are what turned out to be the key learning points or resources for learning (Akkerman & Bakker, 2011).

 doi:10.20944/preprints201804.0062.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

> "I had many questions in my mind on the future and sustainability of this technology. Now slowly the questions are being answered as…such as roaming of livestock immediately after harvesting maize, preparing land for planting maize in the next season in the presence of Desmodium and Brachiaria grass….. Because of the interactions we have had together with other stakeholders over time, I have cleared my doubts*" (PPT Follower farmer, FGD in Bako area, March 2014).*

3.2 Farmer Leadership in Push pull Technology and related activities

The transdisciplinary research using PPT implementation as a process was meant to empower and also enhance leadership through hands-on and joint learning among the farmers in particular. During various activities of PPT implementation, the farmers had frequent interactions with scientists/extensionists, they tended understood and learnt the performance, benefits and challenges of the technology. For the first time, group of farmers who took the initiative and were confident they established PPT on their farms. These farmers are referred as PPT farmers and the rest other farmers who were learning from them were the follower farmers. The PPT farmers turned out to be farmer leaders in their own right through sharing and extending information about to fellow farmers during events such as field days and take on the role as the farmer teachers (Amudavi, 2009a; 2009b) while at the same time playing a key role as key stakeholders in the research process. This statement was echoed by an extension expert:

> "PPT has become a "school feed", produces a lot of knowledge, food to feed us humans and livestock… most farmers resist new technologies, but the model farmers accepted to lead the implementation of PPT for the first time…. Other farmers from other *Woredas* will learn from their example by attending such field day's events which is an important platform for learning and experience sharing" (*Extension expert, Bako Tibet, during PPT farmers' field day Sedan Kite Kebele, March 2014)*.

PPT was introduced into *Woredas* for the first time at the farm level during the period of this study (Table 1). The first farmers who took the initiative to participate in the implementation of the technology became the lead PPT farmers. They also played a facilitator role in ensuring that the researchers, extension and fellow farmers were welcomed and freely interacted in their farms/homes. These farmers can be equated in the category of the opinion leaders (Rodgers, 2003). Opinion leadership is whereby an individual farmer is able to informally influence other farmers to change their behaviors (Cross et al., 2003). This group of farmers was similar to other farmers in their groups. The only exception, they were the first group of farmers who were willing to take new initiative of establishing PPT on their farms for their individual benefits and also for their community in general. This group of farmers easily identified or selected by fellow farmers based on their history of their commitment, initiatives and activeness in sourcing and implementing new information to improve agriculture in their farms. In this study, many other farmers were eligible for participation and indeed implement PPT, but not all of them were ready to start the process at that time. This was mainly associated with the season when the study was implemented. During the season, majority of the farmers had either planted maize, was interested to grow horticultural crops such onions, cabbages and tomatoes or had not access to irrigation. The PPT farmers were growing maize crop during the short rainy season and had access to irrigation waters.

The PPT learning plots were established and placed under the management of the host farmers. This gave them an opportunity to experience the first hand gains of PPT on their farms and knowledge about the technology as compared to fellow farmers who were visiting to learn. The day to day interaction with research and extension experts, new farmers and inquiries, elevated their quest to search and learn more information about the technology. This increased their level of expertise, not only on PPT, but other management skills such as decision-making and communication skills from their greater contacts beyond their immediate surroundings (Rodgers, 2003). Their contact with other stakeholders such as the researchers and extension personnel during the planning and implementation, monitoring and evaluation of the PPT activities, visitors from other countries was a learning journey for them. The information and new knowledge gained by these farmers was hoped to be freely shared with their fellow farmers through social events such as community meetings, market places and even churches. Their social standing in the community through undertaking such new initiatives was also elevated. It was hoped that it could eventually lead to a “critical mass” of learners who were expected to adopt PPT in the subsequent cropping seasons. As time goes by these farmers, combined with to their elevated social status, they turn out to become the opinion leaders on other productive sectors of their community apart from agriculture. Thus it is difficult to evade the conventional wisdom whereby such farmers turn out to be mediators of new development activities into their community. This is an indication that all the farmers are potential leaders from the beginning if they take active role to participate in learning and implementing new initiatives. To be able to illustrate this aspect in detail, I will take an example one of the PPT host farmer.

The PPT host farmer *Kebele* A is an illustration contrary to what is commonly thought that, that lead farmers should be well established with good social standing and well to do in the society in terms of assets and landed property or formally educated. However, this particular case is a farmer aged about 38 years without formal education, no family and land of his own. He lives with his elder brother’s family and among other extended family members. He takes care of his extended family large herd of livestock of over 30 animals consisting dairy cattle, oxen, sheep, goats and donkeys. He rented the land from his brother to plant maize and accepted to participate in the implementation of PPT. He is the most active member of the family despite the fact he has no family of how own. From his active farming and other social activities, he is respected by the community members. He was selected for participation based on his interests as the farmer to take up new initiatives and the respect he had earned himself from fellow farmers in the village.

> "Innovative/model farmer is the one who is ready to accept, learn lessons, pass lessons to other farmers, conduct own research and share with fellow farmers and researchers how technology works on reducing the losses due to stemborers pests" **(***KI small scale irrigation and drainage expert, Bako Tibe, April 2015).*

During further discussion with the irrigation expert, he had the same farmer in mind, from *Kebele* A, he commented that, farmer was always willing to offer his rented farm for trial of new technologies. He is a lead farmer and risk taker and previously he had participated in the establishment of trial plots of other new technologies such as tree nursery for agroforestry and Napier grass nursey for fodder production in his community. PPT is among these initiatives he is keen to try and bring to fruition by working closely with the researchers and extension staff. "Apart from the immediate benefits such fodder, reduced pest infestations and soil conservation properties, PPT is a promising technology" The farmer commented. "He is fully in it and looking forward into the future on what the technology has to offer to him", comment from fellow farmer in the community:

> "The technology is interesting for farmers, researchers and student learning. It addresses complex challenges simply….. Many schoolchildren from around the village are interested to learn how the PPT mechanism works in controlling pests in such a simple way. It is science-simplified and in the hands of farmers. I am able to talk about science-based practice and practically implementing it in my own farm…. " (*Interview with PPT farmer, Bako Tibe, March 2015).*

This particular farmer was able to talk easily and with confidence about the new PPT because he had understood how it works and it was practically existing and implemented on his farm. He took it upon himself to become as a leader in information sharing with fellow farmers and school going students who had interest in learning the technology. The 'teaching' aspect is what motivated and made him pay attention during interaction with researchers and extension staff to learn great detail and later to respond with accurate information to questions was raised by those seeking know more about PPT. Combining with his own intuition with local knowledge and understanding crop-pests interactions and practical observations, he was able to talk about PPT freely and easily. This according to him, it was indeed science demystified (Allen et al., 2014) and gave him an opportunity to become a leader. Apart from

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

stemborer challenges, he was motivated to participate in PPT to address other problems of soil erosion and mono-cropping culture. These practices contribute to soil fertility losses in the area and PPT was seen as a novel idea which was fitting into and has potential to address them. Majority of fellow farmers have no experience or knowledge on cereal crops intercropping practices and are dependent cereal-livestock production systems. They are constrained by perennial fodder shortages. To these type of farmers, PPT was an opportunity to learn and share wide ranging knowledge and practices.

> "Apart from pest control, food and fodder production to environmental conservation, PPT is easy to understand and use despite the underlying scientific principles at play. The resource constrained farmers are not able to afford expensive farming inputs aimed at increasing productivity such as fertilizers and pesticides," (*Interview PPT farmer, Bako Tibe, March 2015).*

Another example is a farmer, from the neighboring village B who had actively participated as lead farmer in other technologies previously introduced in the village, thus his social standing was already elevated. Whenever new opportunities arose, he still stands out to be selected by fellow farmers and local administration as their farmer leader.

> "I have participated in other extension packages such as tomato, onion, and maize production. Am ready to make PPT a model and aesthetic farm in my village. I previously learned from Sasakwa Global2000 farm extension model plot, so am determined. I have become a lead farmer through training and actively trying extension packages. Previously I was selected by the *Kebele* administrator as a model farmer in the village. Am happy with being model farmer, it is rewarding from the certificates of participation and sense of satisfaction either socially or economically.….I have managed to invest in a new house, bought a mule and cart from increased farming income from being a model farmer." (*Interview with PPT farmer, Bako Tibe, March 2015).*

The selection of farmer leaders was undertaken by the other farmers who had trust, confidence and were comfortable to have one of their own to take lead and whom they could learn from. Their elevated social status after participation in new technologies was a motivating factor for other farmers with similar backgrounds to emulate. Although it may seem to be pointing to replicating the 'farmer opinion leadership' where an individual farmer is believed to influence other farmers' attitude and opinion (Rogers, 2003), but farmer participation in PPT was a different. It involved participation of other stakeholders (academic and non-academic researchers) in sharing of their diverse forms of practices,

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

expertise and knowledge on stemborer pest control and their input and contribution to the research process was as a result of joint efforts.

3.3 PPT Implementation: An opportunity to Manage or to Escalate Conflicts?

The introduction and implementation of PPT in the study area had mixed blessings. Not only it brought new knowledge on managing stemborer and other benefits, but also new dimensions of conflicts which were not expected nor existed before.

> "Initially we had an informal agreement on water use and allocation mainly for irrigation purposes. Now with the introduction of PPT, some farmers who didn't understand about the technology started questioning why water was diverted to these plots…This caused us to have irrigation water use conflicts, forcing us to irrigate PPT plots at night with the aid of torch." (*Interview with PPT Farmer, sedan kite Kebele, Bako Tibe, March, 2015).*

The implementation of PPT in the area had contributed to the emergence of water use conflicts which had not been experienced before. The conflict was as a result of using irrigation water in PPT plots as a supplement to low rainfalls in the area during the period of the study. The result may be seen as a negative outcome, but it brought the problem into attention under the ministry of water and irrigation for an intervention. Previously, water use agreements in the area were informally set up among the farmers who were practicing horticultural farming and other users along the Gibbe River. However, with the introduction of PPT, it generated mixed reactions on water use allocation which was on high demand from many users along the river. According to the horticultural farmers and other users, there was no water allocation for PPT. That means, the allocation was causing unnecessary demand on the already scarce irrigation water. Despite the allegations, the PPT farmers attributed these conflicts to jealousy from their fellow farmers. This was because; the PPT farms were outperforming the horticultural crops in terms of productivity and market prospects. Previously, without PPT, some of these farmers were planting maize using the same water and such conflicts were not witnessed. In order to manage the resultant conflict from escalating or recurring in the future, the officials from the Ministry of water and irrigation who were part of the research team, together with other stakeholders, convened a joint meeting and agreed to have a formalized the water use arrangement. This was a bottom up approach of formalization through stakeholder mobilization and engagement. The agreements were put on paper with a clear outlines on who, when, where and amount of water allowed to be used for irrigation along the river taking into consideration of other users downstream on the Gibbe River, which cuts across many *Woredas* in the region. According to Gray (2008), absence of conflict resolution is a detriment to any form of

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

transdisciplinary collaboration which requires integrating of diverse aims and interests among the stakeholders. Leadership with process skills to manage and facilitate conflict resolution plays an important role the success or failure of transdisciplinary efforts (EU SCAR, 2012; Gray, 2008).

Some of the farmers, extension and researchers were skeptical on the introduction of PPT. Some researchers referred Desmodium as a weed introduced into farmland. "Desmodium is an obnoxious weed. When introduced into the farmland, it competes for space and nutrients with the main crop and it is non-edible for humans." A senior researcher at Bako research center made such comments based on the experience he had on intercropping maize using edible legumes such as cow peas and soya beans as protein sources and also improving soil fertility. He had not witnessed the performance of Desmodium as a maize intercrop under PPT.

At the household level, one of the lead farmers in Jimma Arjo *Woreda* area and his wife had a domestic brawl as a result of the introduction of PPT in their farm. The wife heard a rumor that, once established, PPT crops stay on-farm forever, and therefore their land will be taken over by the promoters of the technology. "My wife was skeptical and lost interest in the technology. She felt that I have been misled and sold out the land without her knowledge," the lead farmer comment. To this particular farmer's wife, this was some sort of land grabbing where she could lose access to her land which she previously could grow crops for her family livelihood.

Land is an important resource in terms of investment and food production opportunities for the socio-economic and environmental wellbeing of the owners. So when the same land is acquired by outsiders who are either individuals or companies to serve their interests at the expense of its owners, it can be seen as land grabbing. Under smallholdings in densely populated areas, land grabbing can also take place through introduction of commodity crops by multinational companies e.g. sugar cane, tea, coffee, Jatropha etc. These crops are perennial i.e. they are planted once and remain in the farm over the years. In most instances the owners of the land are poorly informed of the consequences of the investments and growing certain crops on their farms. There are a number of reasons given by the proponents of such land transactions e.g. food production, technology transfer, job creation and infrastructure development in those areas. For example, they argue that, such investments on land will enhance and close productivity yield gaps through the supply of high capital agricultural inputs such as irrigation and other technologies (Anseeuw et al., 2012). With awareness creation and information availability either through media or civil society groups, the farmers are becoming sensitive with new technologies which are tailored or based on land investments. PPT is such an example. It was introduced as a new technology with perennial companion crops planted under smallholder farming systems. At the same time it was being introduced

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

by researchers from other countries. With this type of technology characteristics, PPT can be easily attached to negative rumors linked with land grabbing.

There was no formal Memorandum of Understanding (MOU) among the stakeholders with details on collaborative working arrangements between the researchers and extension staffs from different ministries and departments. The working arrangements were based on individual commitments by the staffs from the different department. However, between partner organizations, it was not smooth running. For example, some of the stakeholders were interested in payments to participate. They were seeing the PPT implementation as not part of their mandate or their acknowledgement was unspecified. Some of the extension personnel and researchers felt that participating in PPT implementation was conflicting with their day-to-day activities unless it was formally arranged. The MOU concerns were necessitated by the fact that previous initiatives on joint stakeholder engagements had not yielded tangible results but limited to boardroom agreements. For example, the Agricultural Development Partners' Linkages Advisory Council (ADPLAC) was meant to strengthen linkages among researchers, extension staff and farmers. However, this has not been easy to operationalize overally due challenges from lack of actor commitment, financial limitations, staff time to frequent transfers turn overs. Therefore, it was hopped that MOU based on PPT activities with specific stakeholders could a better way to learn how to deal with these kind of bottlenecks.

The introduction of PPT in some instances caused conflicts by challenging the locally entrenched practices by the farmers themselves and even the extension and research officials. For example, intercropping maize with an additional crop was commonly practiced among the farmers and some of the extension staff had no experience on how to go about it. In this case, introducing PPT was conflicting with their already entrenched and established culture of mono-cropping. The extension officials were accustomed to the culture of conventional and linear technology transfer as the main source of extension messages. The participatory process of stakeholder planning and implementation of activities on joint basis was seen as a source conflict by some of these officials. The farmers are placed at the receiving end and they are only supposed to implement what have been instructed by the extension or by researchers. Correspondingly, the participation of the landless farmers and private sector/traders in extension services was a not common practice of working with the extension professionals in the study area. The off-season Brachiaria and Desmodium crops management introduced by PPT was a new activity which was conflicting with their long-established tradition of allowing livestock to roam freely after harvesting maize crop in each season. Establishing PPT demanded that, the farmers have to fence off their farms or guard their farms. This was conflicting with the age-old traditional practice. Some of the farmers and the

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

extension staff were doubtful on whether the establishment of PPT could withstand the tramping and overgrazing which takes place when the animals are freely roaming all over the harvested fields scavenging for fodder.

However, the emergence of conflicts as a result of new ideas from PPT, it was embraced and used as an opportunity for in-depth learning about the technology and also to find solutions and its possible adaption. According to (Suchman, 1994), these are the situations requiring boundary crossing and indeed effective leadership to manage the transitions. During an interview with an agriculture extension expert, at the Bako Tibe *Woreda* on what sort of leadership required among the stakeholder teams that will enable successful learning of PPT despite situations where it has conflict with local practices, he said:

> "There is need for flexibility among the collaborative stakeholders. The actors have to understand the needs of others, their potential strengths and capacities. Understanding the needs of the people and working on their minds is challenging…….but, the leaders should be experts who are committed with a guided vision long into the future…" (*KI extension expert, Bako Tibe district, March 2015).*

The joint implementation of PPT by researchers and others stakeholders, especially to the farmers, it came in with new information which was inconsistent with their usual maize cropping practices, thus creating an uncomfortable psychological state due to uncertainty from what the technology had in store for them and were not sure about. However, this can be overcome by working in concert and combining different ways of knowing and learning among different social actors (Siebenhüner, 2004).This challenge stems from the fact that lack of effective communication between such individuals who are not similar may cause cognitive dissonance (Cross et al., 2003). Medlin (2001) indicated that such differences as technical competencies, cultural beliefs, and social status in the community and language barriers may lead to mistaken meaning, thereby leading to distorted or even unheeded messages. Indeed to be able to break or span between these different states, the interaction among the stakeholders on a continuous basis was a necessary input which PPT was expected to provide. Such longevity has been specified, that PPT activities should last at least 2-3 maize cropping seasons for effective performance and learning to take place. This gives sufficient time and allows stakeholders involved to become familiar with each other and adjust their local practices and beliefs to new technology and even the ways of working. This means that the organization and leadership of the process provides the direction towards successful interaction, fruitful collaboration and learning. With notable example of Ethiopia, the organization and implementation of PPT requires institutional changes such as embracing participation by both of non-traditional players such as private sector and youthful farmers who are showing interest in commercial or

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

enterprise based farming activities. This will broaden their collective learning beyond traditional communities and approaches of academic researchers and state run extension agencies. This view was echoed by the key informant:

> "What we have learned so far never existed before on intercropping cereals with Desmodium… The PPT implementation process brings on board other new players such as the farm input sellers, youths and women to contribute to agriculture…During dry season, farmers plant tomatoes, onions and cabbage as horticultural crops using furrow irrigation. This is a new custom of planting maize with Desmodium and Brachiaria grass during dry time." **(***KI agriculture extension expert, Bako Tibe, April 2015).*

3.4 Sustainability of PPT as an Innovation: New Linkages created during the Transdisciplinary Stakeholder engagement

The implementation of PPT is associated with either stemborer pests control, *Striga* seed bank depletion in the soil or provision of fodder for livestock. This is based on the immediate results or the products farmers benefit from practicing PPT. However, beyond these benefits lies the issue of PPT sustainability. Apart from the durability and effective performance of the companion cropping, its sustainability is depended on the strength of relationship and learning processes which occur among the stakeholders, type and nature of new enterprises and activities which are created as a result of its implementation. Equally PPT sustainability concern is whether these activities will continue being implemented by the farmers over successive seasons and fitting or adapting to the already existing cereal crop based farming activities. During this study, new ideas and issues were raised and discussed by the stakeholders regarding the question on sustainability of PPT.

3.4.1 Opportunities for interactions

The transdisciplinary action research and the practical on-farm nature of PPT implementation provided frequent interactions and continuous learning on its workings and even challenges for both researchers and other stakeholders. This was evidenced by their comments:

> "PPT is a unique technology. I think it is sustainable based on its integrated nature, and continuous learning on step by step basis…. There are many questions which can be raised and answered with the introduction of PPT on the farm. The major one being, it is addressing the

serious challenge of stemborer pests in maize production…. Yes, we can have the best breeder seed, best fertilizer, enough rainfall and well prepared field, but without a sustainable, affordable pest control, still productivity will be affected or reduced. You may have all the capital, but if no pest control, you still have low crop yields. In the future, this technology has lots of potentials." (*Interview with Bako researcher, April 2015).*

"PPT is a useful technology for the new generation of farmers. This is because it lasts longer in the field and provides opportunities for continuous learning and interaction…..The farmers have started to understand how environmental factors contribute to pest problems and how the same can be used on their management…." (*Interview PPT farmer, Bako Tibe, March 2015).*

"I had many questions in my mind on the sustainability of this technology. Now, slowly, the questions are being answered" a follower farmer commented during FGD. Farmers like to participate in new technologies which can give them flexibility to improve in their farming enterprises or maximum returns on their investments. For example, the minimum average plot size recommended for PPT is about 600M^2. In the study area, due to population increase, the land is scarce and most farmers own less than two ha of land. PPT plot require management practices which farmers can acquire with time and when convinced with the performance results, they can expand to the entire farm or if not convinced, they can drop the technology. This makes the practice of PPT a learning journey. For example, in the case of *Striga* control, PPT requires up to 6 cropping seasons to have the *Striga* seed bank almost fully depleted from the infested soils (Khan et al., 2008). The benefits such as fodder and stemborer control are witnessed within one maize cropping season. This requires patience to get full benefits and even to make decisions. During the interaction process among the stakeholders, PPT provided opportunities for learning about other farming methods and related enterprises e.g. farmers were able to learn how to plant maize under irrigation. In the past, farmers in the study area have been growing horticultural crops using irrigation. Currently under irrigation the PPT farmers were produce maize for food and additional fodder for their livestock using irrigation. During dry seasons, most farmers don't participate in cereal crop farming and the let their livestock to roam freely scavenging for scant fodder in the harvested fields. This not only affects the production levels of the livestock, but also contributes to environmental degradation through overgrazing and destruction of vegetation cover. Push pull technology had shown the potential that these negative environmental conditions can be addressed and even reversed:

"….Land for grazing is reducing and slowly in-door feeding is gaining currency in the district. Ethiopia has highest number of cattle in the region, but the quality and productivity is poor due to low quality feeding. Therefore, PPT is part of the solution in terms of complementary fodder

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

production for livestock in the area." *Interview, livestock production expert agriculture, Bako Tibe, April, 2015.*

The application of PPT as a method for stemborer pest control had not been used previously by the MOA officials in the study area. Despite this, as decision makers, their commitment and policy support was needed from grass root to national levels of administration. The commitment shown from farmers on learning and willingness use the PPT was an encouragement for the officials to provide the necessary support. This is what culminated to the inclusion of PPT as part of MOA extension and soil and water conservation programs. PPT was included as part of the Ministry's programs Integrated Pest Management (IPM) and also in the soil and water conservation measures. This was because it was complementing the already existing efforts. For example, the MOA officials encouraged farmers to plant Brachiaria grass along the farm borders and slopes and intercropping maize with Desmodium to reduce surface water run-off and prevent soil erosion. In the past, the same program promoted the use of vetiver grass as a cover crop; however, due to the turf nature of its leaves, it is not preferred for harvesting as fodder for livestock. Brachiaria grass was preferred alternative to vetiver grass, which has same growth and conservation properties, but with soft leaves makes it easy for feeding livestock.

The soil and water conservation such as terracing, planting grasses on the hillsides or planting trees in the country are conducted as mass campaigns mainly with long term objectives. The difference with PPT, it was a done on personalized contact with individual farmers and the conservation benefits have both immediate and long term returns e.g. Brachiaria grass providing fodder and stabilizing soil on the hillsides. Despite the fact that the technology was proving as a potential platform upon which both immediate and long term farming enterprises be built, the sustainability question was still lingering in the minds of the stakeholder engagement/research team. To address the sustainability issues of PPT, the team raised and discussed among other issues, on the potential linkages with new market opportunities and also as content for training agriculture students in the technical and vocational centers.

3.4.2 Promoting PPT-based new market opportunities

The implementation of PPT came with new market opportunities for the farmers and other stakeholders to participate i.e. commercially-oriented farming. Some of these farming enterprises include dairy, beef (fattening), commercial seed production and agro-dealership for PPT inputs. The coming together of several actors creates a market place; network of PPT practitioners with a broad-based social capital to draw from and also for learning and dissemination of PPT. As a learning platform, PPT can be used to promote other technologies which have a linkage to it. For example, during off season, the PPT plots had sufficient soil and residual moisture which farmers used it to grow chick pea. The high demand and good market prices for chickpeas in Addis Ababa and other big cities was a strong incentive for other farmers to participate in PPT. This was because, during dry season, only PPT farms in the area had some residual moisture due to soil cover provided by Desmodium. This was an incentive:

> "For the sustainability of this technology, we need to supply seeds for planting and target young farmers and develop local structures on seed supply…… PPT is setting up the pace for accepting other new technologies. We have to use the existing platforms for us to get maximum benefits and, for its sustainability, we have to ensure seed source from own production." (*KI Interview, Women and youth affair affairs expert, Bako Tibe, April 2014).*

Sufficient production and distribution of Desmodium and Brachiaria seeds forms the basic component for sustainable expansion of the technology. The involvement of farmers in PPT seed collection and production is a very important practice towards achieving this goal. This can only be achieved if the farmers and traders will have the interest to invest in seed production and distribution.

> "Bako research center has no mandate to produce and sell the Desmodium seeds; we are only engaged in conducting research and producing breeder seeds. However, we can provide leadership on the distribution of the produced seed i.e., support seed production and coordinate the distribution, but the government authorities should provide guidelines on production and distribution." *(KI Interview, researcher Bako Research center, November 2014).*

> "Farmers in the area know Desmodium as new crop which came from the research centers, it is not an indigenous crop. It was introduced as a fodder and cover crop for livestock and in coffee farms. Farmers at the same time had no knowledge on seed production, processing and selling as a source of income. This is an opportunity for learning and to meet the demands of the new and emerging Desmodium seed market." (*KI interview, researcher Matuu Agric Res Center, March 2014).*

There is huge production potential for silver leaf and modest quantity for green leaf Desmodium from the Yayu and Jimma areas adjoining forests and along the farm hedges. This is an opportunity for the youths and women farmer groups to participate in PPT through Desmodium seed collection as a response to the demand and market for supplying Desmodium seeds for the new PPT farmers in the country. For instance, 3 tons Desmodium seeds were bought by *icipe* in March/April 2015 from the farmers, Metu and Jimma Research Centers, and agro-dealers in Jimma. This was a good incentive for the producers to collect more seeds and an opportunity to generate cash income for the farmers. The market linkage was

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 5 April 2018 doi:10.20944/preprints201804.0062.v1

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

associated as a measure for sustainability of PPT. The private agro-dealers have an existing network of seed collection and distribution and Desmodium is one of the seeds collected and traded. That means, the successful promotion and expansion of PPT will increase their market penetration with Desmodium seeds and this has significant influence on the sustainability of PPT.

3.4.3 Applying PPT knowledge as training content

PPT content is suitable as a curriculum material not only for training farmers, but also for training college students. The participation of college tutors and students during farmers' field days was an opportunity for them to link theory with practical realities on the farmers' fields. This stimulated their interest to learn more with intentions to apply the knowledge when they graduate**.** They learnt that, the technology touches on key sectors of their training: crops, livestock and natural resources management. This was noted by one of the students who participated during the farmer field days:

> "PPT is simple to implement, it is cheap, uses less expensive inputs, it is very important for the livelihood of the farmers. Bako College is a center of excellence for training Development Agents (DAs) in plant science and animal health. Including PPT in our curriculum will be an opportunity for information transfer to the students who will finally become DAs….and will transfer the same knowledge to our farmers." (*Interview, student Bako College, April 2015).*

Bako technical and vocational training college is mandated to train frontline extension staffs, who are otherwise called Development Agents. They are employed immediately after graduating to work as village extension staff. During interview with one of the tutors who attended farmers' field days, he said:

> "In our college, we provide DA's training in two types. That is occupation-based and project-based. The former one is based on Ethiopian occupational standard prepared by Ministry of Education. For the second one, the projects are prepared based on the competencies or topics selected from list of occupations like crop production, animal production and natural resource conservation. The project-based training contains competence, entrepreneurship and technology. So having our curriculum content with technologies like PPT is important for our students who will eventually teach farmers." *(Interview, Bako college tutor, April 2015).*

This statement was backed up by another tutor from the college:

> "PPT field day provides an opportunity for the teachers to learn and have experience with the new technology. Now with practical knowledge, it is easy to read and understand and transfer to learners who will become DAs…. This is a perfect opportunity for introducing the technology as

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

a tool for training and for learning by various disciplines….and seems to touch all the departments…from technology, trade, crops to livestock/health etc." (*Comment by Bako college tutor during farmer' field day, April 2015).*

3.5 Mutual Trust in Trans-disciplinary Stakeholder Interaction: Cultural factor on appreciating new information. Is it dependable under PPT?

The critical basis for stakeholder collaboration and cooperation is trust which is built and maintained through regular meetings, openness, transparency and offering something of immediate importance to the stakeholders (Hornidge et al., 2011). However, building trust is a major practical challenges facing TDR process among the stakeholders with diverse interests, disciplinary backgrounds and experiences. Therefore, attention has to be given to building trust in order to make the process a success. The PPT implementation process follows maize crop phenology and covering several cropping seasons. The stakeholder interaction during these seasons has the potential to generate mutual relationship and agreements and among the stakeholder involved. Sometimes, it can also lead to disagreements. As opined by Cundill et al. (2015), in normal situations, for such interaction to come to a point of developing trust requires some time and sustained interaction. During PPT implementation over successive seasons, the stakeholders have an opportunity to frequently interact and learn over common and emerging issues related not only to stemborer pest control and other farming enterprises, but also strong relationship among the stakeholders.

According to Wenger (2000), people must know each other well enough to be able to interact productively and know who to call for help or advice. They must trust on each other and also have no doubt on their willingness to contribute to the common enterprises of their community. This makes them to feel comfortable and to openly discuss and speak truthfully to each other in an attempt to address their common challenges. In Ethiopia, for example, as an outsider, I made observation that there is a culture of benevolent trust among the people especially in the rural areas. This means that nobody is willing to share information which can lead to harm a neighbor. They may prefer to keep useful information rather than share what is injurious to their neighbors. This is because the consequences will be known and seen an enemy to the other members. This culture makes them share information on new technologies or opportunities which directly are meant address their real life challenges expecting similar response in future. For example, achieving the expected increase in maize production by 4-5ton/ha and provision of high quality livestock fodder which are associated with introduction of PPT, is an incentive of immediate benefit for the farmers and other stakeholders to develop interest and share information regarding the

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

technology. However, at the same time, if these farmers don't trust the source of information, they could easily give up on its benefits. The trust is even higher if the information is from a competent based source i.e the person is knowledgeable about a given subject. Such a culture of appreciating new information from competent based sources and sharing it freely is an entry process to the learning journey. "Farmers easily trust new technologies if it is from competent contacts or sources in the community such as lead farmers, extension staff and researchers whom it is assumed have already tested or put into use before introducing or recommending it to us" comment from a PPT follower farmer during FGD. There may be histories of mistrust or communication barriers between farmers, researcher and extension services providers in the past, however, TDR approach, it may have contributed to some extent to some sort of improved ties between the different stakeholders. Therefore, the researchers, extension staff and smallholder farmers started to work together towards solving a common problem of stemborer pest from the point of trusting each other's contributions. Although building such trust requires time which is longer than the time than this study period, however, some 'sort of ties' prevailed which ensured that implementation process was initiated:

> "I learnt that the Ethiopian farmers are interested to take up and adopt PPT more than Kenyan and Ugandan farmers. It will take a short time to achieve the high adoption numbers due to the fact that we trust new information from competent sources so long as it addresses the problem at hand.**"** **(***Comment by follower farmer who visited Kenya and Uganda exchange visit, FGD, May 2015).*

This observation was based on the fact that PPT technology has been promoted in Kenya and Uganda for longer time than in Ethiopia. The reasons cited for low adoption rate was related to the commitments by the research and extension systems of these countries which had not taken up the technology at policy levels and promotion mainly supply and research led. The Ethiopian ministry of agriculture officials requested for the introduction of PPT into the country from the *icipe* researchers with the support of donors in the year 2012. This signifies high level of trust the MOA officials have on *icipe* researches and also commitment for new information to address the problem of stemborers. However, this dependence on research and extension officers as the main source of information and knowledge on new technologies is not sustainable on the long-run. For example, every year the government sets aside 30 days dedicated for soil and water conservation efforts. The farmers are compelled to participate in digging terraces, planting soil cover crops such as vetiver grasses on the sloppy areas. In most instances, this has degenerated to mistrusts, whereby the farmers don't trust the intention of the government officials whether from research centers or extension services. This is also linked to some of the cases where the DAs are used to collect 'taxes' on behalf of the government. The farmers are forced to cooperate and

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

according to the political power needs. This is completely conflicting with agricultural extension activities where farmers are supposed to be treated with freedom and trusting by the extension agents.

Farmers often have some apprehension new technologies whenever introduced in their localities. Connecting with the previous experiences during SG2000 technology promotion, the farmers were not sure what PPT had in store for them. This was attributed partly to lack of enough information at the initial stages of implementation. However, through continuous interactions with researchers and extension personnel, they were slowly appreciating the technology and learning in detail on how it functions. For example, the farmers had noticed that with their current maize crop, the perennial pest problem of stemborer and birds had dropped:

> "I haven't seen stemborer attack this time round in my maize field…. This is contrary to during the normal cropping season, the stemborer always infest stems and birds always attack the maize tassel…. I think birds are searching for stemborer eggs on the maize tassel, hence breaking it… I hope this Desmodium protects maize from stemborer and from birds…. I will continue to observe this trend in the coming seasons. In future I will make some conclusion". *(PPT Farmer interview, April 2015, Dembi Gobu, Bako Tibe).*

However, this observation did not last long. Towards the end of season, the birds started attacking the maize crop but the effect was less, because the cobs had already matured and it was difficult for the birds to feed on mature maize cobs. This was an advantage to the farmer. This keenness of the farmers to make observation and try to make sense of it either by conducting own research or engaging researchers for further discussions was a significant step towards appreciating the technology. This was not only in addressing the pest problem, but also an opportunity for to learning by seeking answers to 'new observations' made. For example, why the birds did not recognize the maize earlier? Was maize made invisible as a result of intercropping with Desmodium? Some of these questions were raised by the farmers based on the observations made for the first time and during the first cropping season. However for certainty, they decided to continue to follow on this observation for some time and during subsequent seasons. They hoped that after 2-3 years of continuous cropping, they shall have formed an opinion based on the long term observations on the performance of the technology and even make recommendations for changes or adaptations. In the meantime, it came out from the discussions that, there is no scientific method so far for scaring or control birds. Locally the farmers use a cassette tape ribbon which they wind along the orders of the maize field. The hissing sound and reflection produced by the ribbon due to the winds blowing is used scare the birds. However, this is effective for small plots of land, of less than half a hectare (½ ha). On the larger fields, they rely on manual birds scaring away mainly by throwing stones

 doi:10.20944/preprints201804.0062.v1

Peer-reviewed version available at Sustainability 2018, 10, 2378; doi:10.3390/su10072378

into the maize plantation. This lasts for about 2 weeks, after which the maize cobs mature and the birds cannot manage to feed on them. However, during off-season crop, the population of birds is too high and feeding on the grain can be intense within a very short period of time, causing huge loses to the farmer.

4.0 Conclusion

The article shows that effective collaborative leadership and empowerment provides a chance especially for the farmer stakeholders to participate in the technology learning and decision making by enabling them to contribute skills towards development, refinement and adaptation of Push Pull Technology. The personalized interest among the researchers and other stakeholders is linked with the newness and first time introduction of the in the study area in order to partake its emergent opportunities and relationships. Although PPT perennial nature of cropping provides opportunities for empowerment through continuous interaction and learning, it requires committed leadership and institutional engagements during the initial stages of implementation from the researchers and other stakeholders. In the transdisciplinary research process, leadership roles taken by farmers is empowering in terms of their ability to reflect on their own practices and drawing on scientific explanations from researchers. It also enables them take lead in new technology implementation and information sharing in free and easy manner with fellow farmers and other stakeholders. Despite implementation process undertaken on a joint basis, the different stakeholders represented their respective interest group. That means that collaboration with 'personally' committed leadership is most likely to contribute to the sustainability of PPT activities when the personal interests are met first. The immediate PPT benefits will sustain the stakeholder interests and gain their trust for continued interaction and learning about PPT. Market forces and the involvement of private sector players also have a role to achieve this as shown by the interests of individual farmers and traders on Desmodium and Brachiaria seed production, collection and distribution.

The findings shows that, in a situation where there are conflicts, either disciplinary nature or practice based, they should be embraced and become opportunities for in-depth learning, finding solutions and adaptation of rather than being sources of contradictions or misunderstandings about PPT. That means new challenges which come with such new technology should be addressed and developed in situ and used as the essential points of learning for further research or improving practice.

The sustainability of the PPT activities and the transdisciplinary processes requires a longer term evaluation study. That is why a follow ups to this study should be considered to document the changes which occurred. This is based on the fact that, the introduction of PPT as much as it sounded positive and progressive, it was not immediately accepted by the all the stakeholder groups.

Acknowledgement

The authors highly appreciate the financial support received from The German ministry for Technical Cooperation and Development (BMZ) through the international Center for Insect Physiology and Ecology (icipe) for the study. Appreciation also goes to the BiomassWeb project for the coordination and facilitation during field research in Ethiopia. Special thanks goes the farmers, Ministry of Agriculture officials and researchers from the Center for Development research (ZEF), University of Bonn and the Ethiopian Institute of Agricultural research who provided guidance and technical support for the study.

Disclosure statement: No conflict of interest was reported by the authors.

References

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., … Keno, T. (2015). Factors that transformed maize productivity in Ethiopia. *Food Security*, *7*(5), 965–981. https://doi.org/10.1007/s12571-015-0488-z

Abdissa Gemeda, Ethiopian Agricultural Research Organization, & International Maize and Wheat Improvement Center (Eds.). (2001). *Farmers' maize seed systems in western Oromia, Ethiopia*. Addis Ababa, Ethiopia: Ethiopian Agricultural Research Organization : International Maize and Wheat Improvement Center.

Allen, W., Ogilvie, S., Blackie, H., Smith, D., Sam, S., Doherty, J., … Eason, C. (2014). Bridging Disciplines, Knowledge Systems and Cultures in Pest Management. *Environmental Management*, *53*(2), 429–440. http://doi.org/10.1007/s00267-013-0180-z.

Allen, W., Ogilvie, S., Blackie, H., Smith, D., Sam, S., Doherty, J., … Eason, C. (2014). Bridging Disciplines, Knowledge Systems and Cultures in Pest Management. *Environmental Management*, *53*(2), 429–440. http://doi.org/10.1007/s00267-013-0180-z.

Amudavi, D. M., Khan, Z. R., Wanyama, J. M., Midega, C. A. O., Pittchar, J., Hassanali, A., & Pickett, J. A. (2009a). Evaluation of farmers' field days as a dissemination tool for push-pull technology in Western Kenya. *Crop Protection*, *28*(3), 225–235. https://doi.org/10.1016/j.cropro.2008.10.008

Amudavi, D. M., Khan, Z. R., Wanyama, J. M., Midega, C. A. O., Pittchar, J., Nyangau, I. M., … Pickett, J. A. (2009b). Assessment of technical efficiency of farmer teachers in the uptake and dissemination of push–pull technology in Western Kenya. *Crop Protection*, *28*(11), 987–996. https://doi.org/10.1016/j.cropro.2009.04.010

Anseeuw, W., Boche, M., Breu, T., Giger, M., Lay, J., Messerli, P., e t al. (2012). Transnational land deals for agriculture in the global south: Analytical report based on the Land Matrix database Geographica Bernensia. CDE/CIRAD/GIG A, Bern/Montpellier/Hamburg.

Archer, D., & Cameron, A. (2009). *Collaborative leadership: how to succeed in an interconnected world*. Amsterdam: Elsevier/Butterworth-Heinemann.

Assefa, G.A. (1998). Development of maize stalk borer, Busseola fusca (Fuller), in wild host plants in Ethiopia. J. Appl. Entomol. 106, 390–395.

Belay, D. and Foster, J.E. (2010). Efficacies of habitat management techniques in managing maize stemborers in Ethiopia. Crop Prot. 29: 422-428.

Berhanu, K., & Poulton, C. (2014). The political economy of agricultural extension policy in Ethiopia: economic growth and political control. *Development Policy Review*, *32*(s2), s197–s213.

Bortz, J. & Döring, N. (2003). Forschungsmethoden und Evaluation für Human- und Sozialwis-senschaftler. Heidelberg Berlin, Springer-Verlag.

Bracken, L. J., Bulkeley, H. A., & Whitman, G. (2015). *Transdisciplinary research: understanding the stakeholder perspective* (Vol. 58). https://doi.org/10.1080/09640568.2014.921596

Bunders-Aelen, J. G. F., Broerse, J. E. W., Keil, F., Pohl, C., Scholz, R. W., & Zweekhorst, M. B. M. (2010). How can transdisciplinary research contribute to knowledge democracy? In R. In't Veld (Ed.), *Knowledge Democracy – Consequences for Science, Politics and Media* (pp. 125-152). Heidelberg: Springer. DOI: 10.1007/978-3-642-11381-9_11

Bushe, G. R. (2009). *Clear leadership: sustaining real collaboration and partnership at work* (Rev. ed). Mountain View, Calif: Davies-Black Pub.

Chamberlain, K., Khan, Z. R., Pickett, J. A., Toshova, T., Wadhams, L. J. (2006). Diel periodicity in the production of green leaf volatiles by wild and cultivated host plants of stemborer moths, Chilo partellus and Busseola fusca. *Journal of Chemical Ecology*, 32: 565-577.

Chrislip, D. D. (2002). *The collaborative leadership fieldbook: a guide for citizens and civic leaders*. San Francisco: Jossey-Bass.

Crosby, B. C., & Bryson, J. M. (2005). *Leadership for the common good: tackling public problems in a shared-power world* (2. ed). San Francisco: Jossey-Bass.

Cross, R. L., Parker, A., & Sasson, L. (Eds.). (2003). *Networks in the knowledge economy*. New York: Oxford University Press.

Cundill, G., Roux, D. J., & Parker, J. N. (2015). Nurturing communities of practice for transdisciplinary research. *Ecology and Society*, *20*(2). http://doi.org/10.5751/ES-07580-200222

Deneke, T. T., & Gulti, D. (2016). Agricultural Research and Extension Linkages in the Amhara Region, Ethiopia. In F. W. Gatzweiler & J. von Braun (Eds.), *Technological and Institutional Innovations for Marginalized Smallholders in Agricultural Development* (pp. 113–124). Cham: Springer International Publishing.

Dessalegn, Y. (2013). Inter and Transdisciplinary Research Methods: Relevance to rural transformation in Ethiopia. *Inter-and Transdisciplinary Research Methods in Rural Transformation*, 5.

EU SCAR (2012), *Agricultural knowledge and innovation systems in transition – a reflection paper*. Standing Committee on Agricultural Research (SCAR), Collaborative Working Group on Agricultural Knowledge and Innovation Systems (AKIS), European Commission, & Directorate-General for Research and Innovation. Brussels.

Frydman, B., Wilson, I., & Wyer, J. (2000). *The power of collaborative leadership: lessons for the learning organization*. Boston: Butterworth-Heinemann.

Getu, E., Overholt, W.A., Kairu, E. and Omwega, C.O. (2002). Status of stemborers and their management in Ethiopia. Integrated Pest Management Conference Proceedings. 8-12 September, Kampala, Uganda.

Gray, B. (2008). Enhancing Transdisciplinary Research Through Collaborative Leadership. American Journal of Preventive Medicine, 35(2), S124–S132.

Harris, F., & Lyon, F. (2014). Transdisciplinary environmental research: a review of approaches to knowledge co-production. *Nexus Network Think Piece Series, Paper*, *2*.

Henriksen, D. (2011). *We teach who we are: Creativity and trans-disciplinary thinking in the practices of accomplished teachers*. Michigan State University.

Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U., Zemp, E., (2008) Handbook of Transdisciplinary Research. Springer.

Hoppe, R. (2005). Rethinking the Science-Policy Nexus: from Knowledge Utilization and Science Technology Studies to Types of Boundary Arrangements. Poiesis Prax 3, 199-215.

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

Hornidge, A-K, Ul-Hassan, M. & Mollinga, P.P. (2009). 'Follow the Innovation'-A joint experimentation and learning approach to transdisciplinary innovation research. ZEF working paper series, No. 39.

Hornidge, A-K, Ul-Hassan, M. & Mollinga, P.P. (2011).Transdisciplinary innovation research in Uzbekistan – one year of 'Follow-the-Innovation', Development in Practice, 21(6), 834-847.

Hurni, H. (1998). Agroecological Belts of Ethiopia. Explanatory Notes on Three Maps at a Scale of 1, 1. Soil Conservation Research Programme, Research Report.*Journal of Technology and Globalisation, 2*(3/4), 279-287.

Khan Z. R, Hassanali A, Overholt W, Khamis TM, Hooper AM, Pickett AJ, Wadhams LJ, Woodcock CM. (2002). Control of witchweed Striga hermonthica by intercropping with Desmodium spp., and the mechanism defined as allelopathic. Journal of Chemical Ecology 28, 1871–1885

Khan, Z. R., Midega, C. A. O., Amudavi, D. M., Njuguna, E. M, Wanyama, J. W., Pickett, J. A. (2008). Economic performance of the ''Push-pull'' technology for stemborer and Striga control in smallholder farming systems in western Kenya. Crop Protection, 27: 1084-1097.

Khan, Z. R., Midega, C. A. O., Wadhams, L. J., Pickett, J. A., & Mumuni, A. (2007). Evaluation of Napier grass (Pennisetum purpureum) varieties for use as trap plants for the management of African stemborer (Busseola fusca) in a push?pull strategy. *Entomologia Experimentalis et Applicata*, *124*(2), 201–211. https://doi.org/10.1111/j.1570-7458.2007.00569.x

Khan, Z. R., Midega, C. A., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J., & Pickett, J. A. (2014). Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639), 20120284.

Khan, Z. R., Pickett, J. A., Van den Berg, J., Wadhams, L. J. & Woodcock, C. M., (2000). Exploiting chemical ecology and species diversity: stem borer and Striga control in maize in Kenya. *Pest Management. Sci*ence, 56: 957-962.

Khan, Z. R., Pickett, J. A., Wadhams, L.J., Hassanali, A., Midega, C. A. O. (2006).Combined control of *Striga hermonthica* and stem borers by maize-Desmodium spp. intercrops. *Crop Protection,* 25:989-995.

Kohler, T., Fueller, J., Matzler, K., & Stieger, D. (2011). Co-creation in virtual worlds: the design of the user experience. *MIS Quarterly*, *35*(3), 773–788.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., … Thomas, C. J. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, *7*(S1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Linden, R. M. (2002). *Working across boundaries: making collaboration work in government and nonprofit organizations* (1st ed). San Francisco, Calif: Jossey-Bass.

Medlin, B. D. (2001). *The factors that may influence a faculty member's decision to adopt electronic technologies in instruction*. Virginia Polytechnic Institute and State University.

Miller, T.R., T.D. Baird, C.M. Littlefield, G. Kofinas, F. Chapin, and C.L. Redman (2008). Epistemological pluralism: reorganizing interdisciplinary research. *Ecology and Society* 13(2): 46.

Mobjörk, M. (2010). Consulting versus participatory transdisciplinarity: A refined classification of transdisciplinary research. *Futures*, *42*(8), 866–873.

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

Mobjörk, M., & Centrum för urbana och regionala studier. (2009). *Crossing boundaries: the framing of transdisciplinarity*. Örebro: Centrum för urbana och regionala studier, Örebro universitet.

Nowotny, H., Scott, P., Gibbons, M. (2004) Re-thinking science. Knowledge and the public in an age of uncertainty. Polity Press, Oxford.

Popa, F., Guillermin, M., & Dedeurwaerdere, T. (2015). A pragmatist approach to transdisciplinarity in sustainability research: From complex systems theory to reflexive science. *Futures*, *65*, 45–56. https://doi.org/10.1016/j.futures.2014.02.002

Reid, R. S., Nkedianye, D., Said, M. Y., Kaelo, D., Neselle, M., Makui, O., … Kristjanson, P. (2016). Evolution of models to support community and policy action with science: Balancing pastoral livelihoods and wildlife conservation in savannas of East Africa. *Proceedings of the National Academy of Sciences*, *113*(17), 4579–4584.

Rogers, E.M. (2003). Diffusion of innovations (5th ed.). New York: Free Press.

Rosenfield, P. (1992). The potential of transdisiplinary research for sustaining and extending linkages between the health and social sciences. *Social Science and Medicine*, *35*(11), 1343-1357.

Schäpke, N., Omann, I., Wittmayer, J. M., van Steenbergen, F., & Mock, M. (2017). Linking transitions to sustainability: a study of the societal effects of transition management. *Sustainability*, *9*(5), 737.

Siarta, S., Blochb, R., Knierima, A., & Bachingerb, J. (2012). Development of Agricultural Innovations in Organic Agriculture to adapt to Climate Change–Results from a Transdisciplinary R&D Project in North-eastern Germany. In Producing and reproducing farming systems. New modes of organisation for sustainable food systems of tomorrow. 10th European IFSA Symposium, Aarhus, Denmark, 1-4 July 2012. International Farming Systems Association.

Siebenhüner, B. (2004). Social learning and sustainability science: which role can stakeholder participation play? Int. J Sustain Dev 7:146–163.

Star, S.L. and Griesemer, J.R. (1989). 'Institutional Ecology, 'Translations' and Boundary Objects: Amateurs amd Professional in Berkeley's Museum of Vertebrate Zoology, 1907-39' Social Studies of Science, 19: 387-420.

Stauffacher, M., Flüeler, T., Krütli, P., Scholz, R. (2008) Analytic and Dynamic Approach to Collaboration: A Transdisciplinary Case Study on Sustainable Landscape Development in a Swiss Prealpine Region. Systemic Practice and Action Research 21, 409-422.

Stellmacher, T., Grote, U. (2011). Forest coffee certification in Ethiopia: Economic boon or ecological bane? ZEF Working Paper Series, No. 76.

Suchman, L. (1994). Working relations of technology production and use. *Computer Supported Cooperative Work*, *2*, 21–39.

Tsanuo MK, Hassanali A, Hooper AM, Khan ZR, KaberiaF, Pickett JA, Wadhams L.J., (2003). Isoflavanones from the allelopathic aqueous root exudates of Desmodium uncinatum. Phytochemistry 64, 265–273.University Press.

Ul-Hassan, M., Hornidge A-K, van Veldhuizen, L., Akramkhanov, A., Rudenko, I. and Djanibekov, N. (2011). Follow the Innovation: *Participatory Testing and Adaptation of Agricultural Innovations in Uzbekistan-Guidelines for Researchers and Practitioners*. Center for Development Research (ZEF), University of Bonn, Germany.

Peer-reviewed version available at *Sustainability* **2018**, *10*, 2378; doi:10.3390/su10072378

Wenger, E. (2000). Communities of practice and social learning systems. *Organization*, *7*(2), 225–246.

Wenger, E., McDermott, R., and Snyder, W. (2002). Cultivating communities of practice: a guide to managing knowledge. Harvard Business School Press.

World Bank (2006). Enhancing Agricultural Innovation: How to Go Beyond the Strengthening of Research Systems. The International Bank for Reconstruction and Development, The World Bank.

Wright Morton, L., Eigenbrode, S. D., & Martin, T. A. (2015). Architectures of adaptive integration in large collaborative projects. *Ecology and Society*, *20*(4). https://doi.org/10.5751/ES-07788-200405