*Type of the Paper (**Article**)*

Empowerment and Tech Adoption: Introducing the Treadle Pump Triggers Farmers' Innovation in Eastern Ethiopia

Shimelis Beyene1, Teshome Regassa1*^, Belaineh Legesse2, Martha Mamo1^, Tsegaye Tadesse3^

[1] Department of Agronomy and Horticulture, University of Nebraska, Lincoln, Nebraska, United States of America; sbeyene2@unl.edu, mmamo3@unl.edu

[2] School of Agricultural Economics and Agribusiness Management, College of Agriculture and Environmental Sciences, Haramaya University, Haramaya, Ethiopia; belaineh.legesse@gmail.com

[3] National Drought Mitigation Center, School of Natural Resources, University of Nebraska, Lincoln, Nebraska, United States of America; ttadesse2@unl.edu

* Correspondence: tregassa2@unl.edu; Tel.: +x1-402-472-1489

^ Daugherty Water for Food Global Institute Faculty Fellow

Abstract: In 2013, thirty-eight treadle pumps (TPs) were installed as low-cost technology introduction for small-scale irrigation in eastern Ethiopia. The pilot project also included training of selected farmers on well excavation, installation and maintenance of pumps. In June 2015, researchers visited nine of the 38 TP sites, and found only two functional TPs. The rest were replaced with a new technology. Farmers who adopted the new technology stated that the limited water output and high labor demand of the conventional TP did not optimally fulfil their irrigation water requirements. The new hybrid technologies have spread quickly to more than one hundred households due to three key factors. First, farmers' innovative modifications of the initial excavation technique addressed the discharge limitations of the conventional TP by excavating boreholes with wider diameter. Second, community ownership of the new technology, including local skills used in well drilling and fabricating excavation implement, made the new irrigation technology affordable and accessible to a higher number of households, leading to faster diffusion of the technology. Third, this innovation has spread organically without any external support. Adoption of the new technology enabled some farmers to accumulate enough resources to diversify their livelihoods into non-farm activities.

Keywords: irrigation; technology adoption; farmers' innovation; diffusion

---

1. Introduction

In Ethiopia, smallholder farmers contribute to more than 90% of all the agricultural production and cultivate over 96% of the total arable land [1]. Thus, agricultural growth has the potential to contribute not only to food security, but also to poverty reduction and livelihood improvement for the rural population. This is particularly true in light of the high yield gap between potential and the actual agricultural production in Ethiopia as compared to the rest of the world [2]. Almost all smallholder farming in Ethiopia is rain-fed [3]. Erratic rainfall and recurrent drought exposes the majority of the rain-fed farming population to food insecurity and perpetual poverty [4], and negatively affect the economy of Ethiopia [5]. Given the rapid population growth and low level of current food production, the country cannot meet its food deficit through rain-fed production alone [6]. Even during relatively good rainfall years, the survival of about 10% of the population depends on external food assistance [7]. Furthermore, climate change is expected to exacerbate extremes in weather patterns and rainfall variability [8]. Paradoxically, the highlands of Ethiopia receive very

 doi:10.20944/preprints201805.0108.v1

high amounts of rainfall, with annual runoff volume of up to 122 billion m3 of water from 12 major river basins. The region also possesses an estimated ground water potential of 27 to 40 billion m3 [3,9-11]. However, lack of water storage structures [5], weak water management governance, and poor implementation of water use and management policies in Ethiopia have limited realization of the economic potential possible from the abundant water resources [12].

The government, recognizing the economic and livelihood importance of agriculture, expresses commitment to solve this paradox through an agriculture focused development program that also includes irrigation development as one of the major strategies [13]. Key government documents such as the Water Resources Management Policy [14], Water Sector Strategy [15], and the country's Growth and Transformation Plans have all emphasized irrigation development as crucial to ensure food security, reduce poverty, and improve the broader national economy [16]. Small-scale irrigation development is widely viewed as having great potential for improving livelihoods of rural households and facilitating adaptation to climate change [17]. As rural households constitute more than 80% of the population [17], significant effort is being made by Ethiopian government and its development partners to expand irrigated agriculture, including small-scale irrigation [18].

1.1. Small Scale Irrigation in Ethiopia

Similar to other parts of sub-Saharan Africa [19], data on small-scale irrigation in Ethiopia is very limited [9]. It is estimated that current irrigated area covers only about 5-6% of the total estimated 5 million hectares considered suitable for irrigation [20,11]. The Ethiopian government has introduced new irrigation technologies for small-scale irrigation that include rainwater harvesting, ponds, hand-dug-wells and stream diversions. Depending on the spatial position of the farm plots and the water sources, farmers are introduced to the use of gravity irrigation, manual water lifting devices, treadle and powered pumps to irrigate their crops [18,21]. Because of the enhanced productivity, relative to rain-fed farming, governmental and non-governmental development actors have invested considerable effort and resources to support adoption of irrigation by smallholder farmers [18]. Introduction of treadle pump (TP) system in Haramaya Woreda (district) of East Hararghe is one of such efforts.

1.2. Project Background

In 2010 and 2011, baseline information collected for a long-term collaborative, food security research project revealed high demand for access to irrigation among study households in two of the most drought prone regions in Ethiopia: East Hararghe Zone and South Wollo Zone [22]. In 2012, the project sponsored iDE Ethiopia to explore the feasibility of installing TPs in study sites with high ground water potential. An inventory of shallow ground water levels in both Hararghe and Wollo preceded installation of the TPs, to select sites accessible by manual water lifting devices such as TPs. In Wollo, small-scale irrigation practices are mainly based on river/stream diversions, springs, lakes and ponds. Hand-dug shallow groundwater wells usually serve community water supply for domestic consumption. By contrast, in Hararghe, Haramaya Woreda, groundwater based irrigation is widely practiced. However, even in Haramaya, households are at different levels in their irrigation practices and technologies they employ. Most irrigating households use simple open shallow wells (Figure 1), while few use wells with concrete casings with motorized pumps. Results of the feasibility assessment revealed that overall there was greater potential, interest, and experience in accessing shallow groundwater for irrigation in Hararghe than in Wollo. Hence, the TP intervention was piloted in Haramaya Woreda in the East Hararghe Zone of the Oromia Region.

Between 2012 and 2013, a total of 55 wells were drilled in Haramaya Woreda as a pilot project (3 wells around Bate town, 9 wells in Damota, 6 wells in Fenkele, 7 wells in Tenike, and 30 wells in Tuji Gabissa kebeles). Out of the 55 wells drilled during the pilot project, 38 wells were successful.

Figure 1. Open shallow well (Photo by authors)

The remaining 17 wells were unsuitable due to stone impediment, insufficient and/or absence of permeable layer, and static water level being too deep for manual pumping. The depth of the wells drilled ranged from 15 to 32 meters and the average well depth was 22 meters. For the successful 38 wells, foot-operated Suction Only Treadle Pumps (35) and hand-operated Rope & Washer Pumps (3) were installed in the five kebeles. Farmers were trained in basic operation and minor maintenance of these pumps. During the project, six individuals, selected from the community, took a rigorous training on well drilling and pump installation. Although the training mainly focused in manual well drilling, it also included skills on well casing installation, maintenance of wells, installation and maintenance of pumps. The trainees, hired as daily laborers during the project, participated in excavating and installing TPs and quickly attained the skills required to maintain the wells and service the equipment for proper function. After the completion of the pilot project, these trainees, in collaboration with local artisans, were capable of producing locally manufactured replacement parts and excavation tools modified from the original implements. These local entrepreneurs proceeded to install modified technologies based on farmers' needs and willingness or ability to invest in additional technological solutions.

The TP technology, although very low in capacity, was an improvement over the preexisting farmers' irrigation practices in the study sites. The assumption was that TPs would minimize the dependency of local farmers on harvesting water in big and open hand-dug wells, with diameters of up to 20 meters. These wells created large soil disturbances and required costly clean-up, using both human labor and excavators when the water level drops during the dry season, to remove accumulated sediment. Moreover, these open wells pose perpetual danger to human and livestock. This preliminary assessment was therefore conducted to: (a) evaluate the status of TPs installed in 2013, (b) explore farmers' views on their TP use and adoption experience, and (c) assess impacts of TP use.

In order to get a variety of perspectives, several irrigated farms were observed. Discussions included farmers, development agents, government officials, NGOs staff, researchers, and local experts in the study area of Haramaya Woreda. A wide range of irrigation practices in terms of technologies, management arrangements, crop types, and scales of operation was observed. This article focuses on local innovations in drilling technology for small-scale irrigation that has become wide spread in Haramaya Woreda.

Conceptual framework for agriculture technology adoption

Improved agricultural technologies have the potential to enhance productivity, income and food security for the majority of the population in developing countries. However, the rate of improved technology adoption is slow, particularly in Africa [23,24]. Even when smallholder

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2018 doi:10.20944/preprints201805.0108.v1

farmers adopt a technology, they may not adopt it immediately or may dis-adopt it after the initial trial period. Often only a certain segment of the population adopts the technology and only on a small portion of their land, especially during the initial trial period [25]. Attempts to understand the constraints of agricultural technology adoption have led to the proliferation of the literature on 'determining factors' [23,26-32]. Some of the widely reported factors that influence agriculture technology adoption and diffusion reported from these studies include: wealth, access to capital, education level, access to labor, perception of risk, tenure security, access to market, social network, and social learning [33]. Depending on farming context [34], a combination of these and other factors may influence the adoption and diffusion of agricultural technology in a variety of ways. For example, many studies have shown that larger landholding is likely to lead to higher adoption rate. This finding is often attributed, among other things, to risk tolerance [35]. Conversely, there is also some evidence indicating the reverse may be valid [36]. For example, the higher adoption rate of improved pigeon peas seeds, in Tanzania, by farmers with smaller landholdings is attributed to the need to intensify due to land pressure [36]. In some studies, the size of landholding may be positively associated with adoption of one technology, and negatively correlated with another [37]. The search for what influences farmers' decision-making in adopting new technology has led to a wide variety of associated factors as aptly summarized by [38].

One of the most influential theories in agricultural technology adoption is the theory of 'diffusion of innovations' by Everett Rogers [32]. Rogers' diffusion of innovations theory is the most appropriate for investigating the adoption and subsequent fate of the TPs introduced in Eastern Ethiopia. This theory explains not only how innovations are adopted and spread through a population, but also how they are modified or altered during implementation. According to Rogers [32], five features of an innovation (a technology, an idea or a practice) influence the speed with which it spreads within a population. These features include: (a) the level of improvement the innovation provides relative to the old practice, (b) the compatibility of the innovation with the existing practice and values, (c) the ease and simplicity of using the innovation (trialablity), (d) the ability of users to test or experiment with the innovation, and (e) the ease and speed with which farmers can see benefits.

2. Materials and Methods

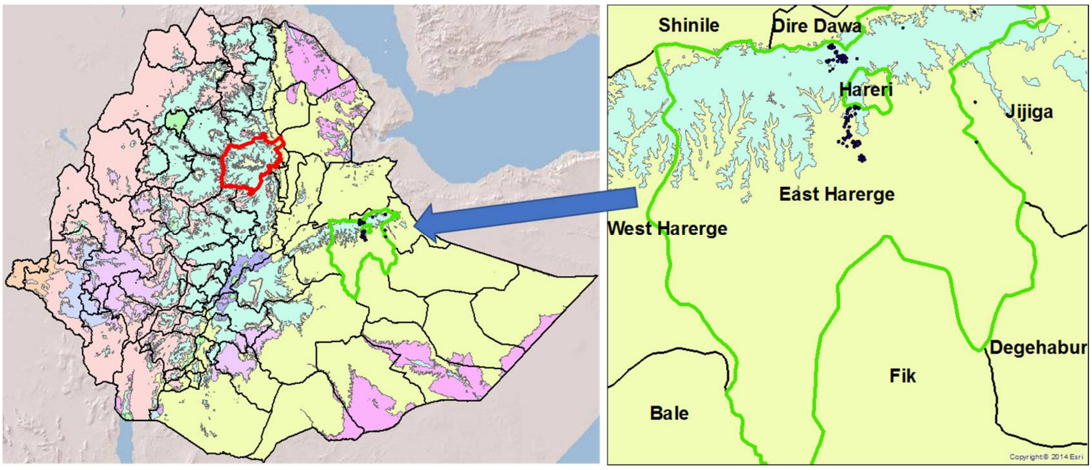
Study Areas

Haramaya Woreda is located in East Hararghe Zone of Oromia Regional State. The capital town, Haramaya, is located about 500 km from Addis Ababa. Haramaya has 33 rural and two urban kebeles (subdistricts) with a total population of 220,986 [39]. Most of the kebeles, including those selected for this study, are considered highland and mid-land. The average annual rainfall, based on 25 years of data from the Haramaya meteorological station, shows a mean total annual rain fall of 775 mm [40]. Although the amount and pattern vary locally, rainfall is bimodal in distribution; a short season from March to May is known as belg, and a longer rainy reason from July to September is known as meher. The maximum and minimum mean annual temperatures for the area are 23.8 °C and 9.6 °C respectively [41]. The area is characterized by frequent drought, crop failure, severe land degradation, and increased vulnerability to chronic food insecurity. The major crops grown are sorghum and maize under rain-fed conditions, as well as Khat, potato, and vegetables, e.g., lettuce, carrot, onion, tomato, and cabbage, under irrigated conditions [42]. Although drying up, Lake Haramaya and shallow, ground water (6 to 30 m deep) in the dry lakebed and catchments provide the opportunity to access irrigation for the households that can afford the irrigation infrastructure [43].

Data Collection

This study was conducted in three selected kebeles within Haramaya. These sites are part of research areas selected for a long-term multi-disciplinary, collaborative research program involving three universities: University of Nebraska, Haramaya and Wollo Universities. The partners are engaged in a system approach to address agricultural productivity, food security and nutrition in two drought prone areas; South Wollo and East Hararghe in Ethiopia (see Figure 2). Qualitative fieldwork and extensive quantitative surveys were conducted in 2010 and 2011, respectively, to provide baseline information for the program [22]. Subsequent fieldwork focusing on small-scale irrigation in Haramaya was carried out in 2012 and 2013 to assess areas suitable for installing TPs for household-based, small-scale irrigation.

Figure 2. Map of Ethiopia showing the study areas.



Before the actual interviews and measurements were made, enumerators obtained informed consent from all participants or parents of children. The University of Nebraska Institutional Review Board reviewed and approved the study protocol and all supporting documents (IRB Approval #: 20100710992EP).

Focus-Group Discussion: Focus-group discussions (FGD) were conducted with farmers from eight different field sites. The size of a group differs from site to site ranging from three to nine farmers of mixed gender, as determined by the number of people available in the proximity of their farm plots. Farmers generally did not have prior knowledge of the visit. Points of discussions covered a wide variety of issues but focused on farmers' perceptions of TP irrigation experience, impacts (both negative and positive) of TP irrigation, cropping patterns, use of inputs (seeds, fertilizers, pesticides), concerns related to irrigation practices and institutions related to water use and management.

Key Informant Interview: Key Informant Interviews (KII) were held with government officials (in zonal and woreda offices), development agents, local well drillers, technical experts, NGO staff, researchers, university officials and local elders. The KIIs included semi-structured interviews covering information, among other things, on aggregate data on irrigation in each woreda, policies and practices related to irrigation development, institutional support to farmers and market-related and natural resource (e.g., water) management issues.

Field Observation: During farm visits, observations were made on the status of the irrigation schemes, major crop types grown on irrigated fields, cropping patterns (strip or intercropping), cropping cycles, irrigation methods used (flood, furrow or other), climatic impacts (frost), plant pests and disease pressures and use of TP systems and the new technology.

3. Results and Discussion

In East Hararghe Zone, the major source of water for irrigation is groundwater. Nevertheless, irrigation practices using wells, open pits, and ponds were observed, indicating that the form in which irrigation water is available dictates how it is used for irrigation. The management of these small-scale irrigation schemes also varied considerably. Similar to the observations in other parts of

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2018 doi:10.20944/preprints201805.0108.v1

the country, irrigation is primarily used for vegetable and high value cash crops in East Hararghe. The major vegetable crops include onion, potato, tomato, carrot, beets, and various leafy greens. Khat, a perennial shrub produced for its stimulant leaf and soft buds, is often an upper canopy intercrop that benefits from the irrigation of under story annual crops. Farmers dedicate irrigation plots primarily to market oriented high value crops, although it is common to observe a portion of irrigated plot used for the production of subsistence crops during one of the cropping cycles.

Farmers visited in East Hararghe used furrow and flood irrigation with motorized pumps. They pump the water directly to the fields using large hoses or to a reservoir (3000 to more than 10000 m^3 in volume) and distribute the water from the reservoir to fields (Figure 3). Sometimes, they also have a series of reservoirs and pumps that can take the water more than half a kilometer away from the original source.

Figure 3. Water pumping to a reservoir (Photo by authors)

The extraction of underground water was so wide spread in Haramaya Woreda, farmers often express fear of ground water depletion due to excess extraction. The unsustainable use of water is a concern of all stakeholders in the area due to the drying up of Lake Haramaya and gradual receding of ground water depth. *3.1. Subsection*

3.1. Farmers Perception of Irrigation

The majority of farmers were enthusiastic about using irrigation. Farmers who have access to irrigation explained their resulting:

- Ability to cultivate two or three times per year (intensification);
- Ability to grow high value cash crops for income generation;
- Ability to build assets (oxen for plough or milk cows);
- Ability to meet some of their financial needs (for children education, health care, and better homes to mention a few);
- Ability to expand irrigation;
- Minimized risk from drought; and
- Improved well-being of families and community at large compared to their lives before irrigation.

All farmers that have practiced irrigation for at least two cropping cycles mentioned improved production and increased income. However, farmers also explained the challenges they face in their effort to realize the full potential of irrigation agriculture as described below.

3.1.2. Major Challenges for Irrigation Farmers

Seeds In all areas visited, farmers stressed the shortage of seeds. Even when available, seeds are often expensive and/or of very poor quality. Farmers stated that they sometimes travel more than 500 km, as far as Addis Ababa, to purchase vegetable seeds with no guarantee of seed quality. Sometimes, farmers could obtain seeds from government or research institutes. However, the amount was insufficient, obliging farmers to purchase additional seeds from different, oftentimes informal sources. Farmers view their inability to access quality seeds as the highest risk factor in attaining the benefit of irrigation.

Market Price fluctuation is one of the most significant problems farmers face, often leading to losses. Good carrot price in one year encouraged the expansion of carrot production; however, as production increased, demand declined, price decreased, and many farmers lost significant amounts of money. Another crop commonly affected by price fluctuation is tomato. Tomato farming is risky because of high farm management cost, price fluctuation and the inability of farmers to keep the product fresh for long. The second issue related to markets is the lack of 'modern' markets. In most areas, farmers have to transport their produce to local, open-air markets, where the volume they can sell is limited. For example, farmers in East Hararghe mentioned that occasionally, they had to discard excess vegetables, such as tomatoes, if they were unable to sell in the open market.

Other Issues Although seeds and markets were the major concerns, crop pests, diseases and weeds were also common concerns raised by farmers. Various pests, some encouraged by inefficient use of irrigation, cause significant damage to crops, discouraging farmers from trying new practices. Some weeds, especially grassy weeds, demand high manual labor to remove them. Often farmers have to hire additional labour for weeding, leading to seasonal shortage of labour and high labour cost. Frost is a major problem from October to January on the exposed, hilly side of Highlands above 2000 m asl. Timing of the cropping cycle is critical in this area, making irrigation even more important. In Tuji Gebissa, for example, frost has forced farmers to convert their perennial Khat plots into vegetable crops in some hilly areas.

Farmers and others (officials and experts) are in agreement with issues related to markets and agricultural inputs, but differ in most other issues. Experts and government officials believe that current irrigation practices use water inefficiently, perhaps related to limited irrigation experience. This may be accurate, especially for furrow and flood irrigation. They also expressed concern related to 'cultural inertia'. For example, in many areas, it is culturally unacceptable for a farmer to rely on purchased grain for its own household consumption. Farmers, therefore, use part of their plots, or one of the irrigation cycles, for subsistence crops, such as corn, barely teff, pulses, etc. Experts view such practice as relinquishing the opportunity to grow high value crops, while farmers perceive it as insurance for food security. Farmers and experts can also be at odds with farming practices. For example, experts believe optimum spacing would produce larger and higher quality onions in irrigated farms, while farmers prefer small sized bulbs from more crowded planting to meet the preferences of customer in the open local markets. Despite these challenges, farmers view irrigation farming as key to improving their livelihoods. The ability to produce a diversity of crops and multiple times per year outweighed the challenges according to the farmers.

3.1.3. Farmers' Innovation in East Hararghe

This study focused on sites where nine of the 38 TPs were installed and where farmers were available for interview during research visits. Most of the TP component systems were partially or entirely replaced by locally modified technology. Farmers stated that the TPs had two primary limitations:

1. Limited capacity of water lifting – farmers mentioned that the area that can be irrigated with TP is at most 50 by 50 meters, which was too small for most farmers' needs.
2. High demand for labor – the manual operation of the TP required high labor input for the small amount of water output.

Figure 4. One of still functional treadle pumps (Photo by authors)

For these two reasons, among the nine TP sites observed, only two were still functional (Figure 4). The other seven had been replaced by locally modified technology. Furthermore, of the two TPs that were still functional, one was being used as a supplement to a new system installed about 5 meters away, and the other owned by an elderly farmer. One of the female farmers who recently moved to the new technology acknowledged the significant impact of the TP. She stated, "the TP has enabled me to compete with male farmers" and that she would not be in the position she is now, if she did not have the TP.

3.1.4. Local "Reinvention": The New Technology

During the project implementation phase, one of the interventions included training selected community members on construction and maintenance of TP systems. Thus, the area irrigation branch of the ministry of agriculture, in collaboration with Haramaya University and an IDE Ethiopia expert, trained six individuals in drilling of boreholes and installing casings, hoses and pumps. This training aimed to build local capacity for maintenance of installed TP systems or installation of new ones if the demand would arise. However, although the local demand for drilling wells was high, a demand existed for a higher capacity system, which the newly trained individuals were able to meet. This local innovation had four main components: wider diameter boreholes, efficient excavation tools, local manufacturing, and effective casing.

Wider diameter of borehole: One of the limitations of the TP technology is the narrow diameter of the well. According to farmers, the TP borehole of 4 cm in diameter was too small to conduct enough water to irrigate an average household plot. The farmers trained during the pilot project were now able to excavate wells with a diameter of 13 cm, which, depending on the discharge rate of the well, can deliver three times more water than the original TP. This diameter seems optimal for Haramaya households, where the average landholding is about 0.5 hectares [22].

Locally constructed tools: The need to increase the diameter of the well required a different sized drilling tool than the one used originally for TP systems. The trained individuals, in consultation with the local artisan, were able to design a more efficient auger with a wider diameter and serrated edges. These augers, developed by local artisans, were used to excavate wider boreholes to provide a larger volume of water than the TP system could provide, meeting farmer's demands.

Cost effective casing: One of the major problems to accessing underground water for irrigation in Haramaya Woreda was the collapsing of well walls, due to the nature of the soil in Haramaya. That is also the reason for high diameter of the open pits wells in the woreda. Once again, the trained

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2018 doi:10.20944/preprints201805.0108.v1

farmers were able to innovate by using cost effective, plastic casing for the new system to function properly.

Figure 5. Controlled excavation for a treadle pump system (Photo by authors)

Between 2013 and 2015, community members trained during the pilot project constructed more than 100 new systems. Furthermore:

- The new system costs 250 to 400 USD. Farmers used to pay more than 1,000 USD for excavation of traditional water pits. One particularly large water pit, shared by 21 individuals, cost nearly 2,000 USD. Traditional water pits are not only expensive to construct and maintain, as the walls cave in frequently, but also take more land that could be used for cultivation.
- Since the introduction of the TP system, farmers reported doubling of crop production. Using the new system, they reported increases in income from an estimated 2,000 USD to 4,500 USD annually (Focus Group Discussion in Tuji Gebissa, June 13, 2015).
- According to farmers, the new excavation techniques go deeper, up to 30 meters, while the initial TP excavation could reach a maximum depth of only 20 meters.
- The observed new or hybrid systems can support up to 10 households, with an average of six individuals per household. This, according to farmers, is ten times more than the original TP system.

It may be instructive to see our preliminary observation through the framework of Rogers' diffusion of innovation theory [32] particularly the five attributes that influence the rate of adoption: relative advantage, compatibility, complexity, trialability, and observability. First, with respect to relative advantage, it is clear that both in terms of water output and reduced labor demand, the new technology is considered advantageous over both the TP system it replaced and the traditional pit well irrigation system. Second, the technology is consistent with values, experiences and needs of farmers in Haramaya Woreda, where about 60% households were engaged in some form of irrigation prior to the pilot project [22]. Third, the unique aspect of the new technology in Haramaya is that it was a local innovation, which makes the 'complexity attribute' [32] a nonissue. The relatively rapid spread of the innovation is an indication of its ease of use for local farmers. Fourth, regarding trialability, the rapid diffusion of the innovation and the preliminary nature of our study preclude the proper assessment of this attribute. The training of selected farmers and their participation in installing the TP systems can be considered trialing without cost to them. It is also fair to assume that the close social network of farmers in Haramaya would allow the rapid dissemination of information about the nature of the TP as well as the new technology experiences across the woreda and beyond. Finally, in terms of 'observability', the results of the new technology will be apparent at least to neighboring farmers immediately. The same mechanism mentioned for rapid dissemination of information mentioned above, would also enhance observability of the results to distant farmers. Moreover, the proximity of the study kebeles to the University and Woreda Extension Office, two entities that have interest to associate with the farmers' success story, could have helped.

Another insightful contribution by Rogers [32] is the concept of "reinvention" – "the degree to which an innovation is changed or modified by a user in the process of its adoption and implementation" (p. 180). He argues that although experts and development agents do not generally see reinvention as desirable, a higher degree of reinvention often leads to faster rate of adoption as reinvention makes the innovation fit to a broad range of adopters' conditions [32]. As reinventions enhance the fit between an innovation and adopters' needs, they are likely to lead to the continued use of the innovation, hence to the sustainability of the innovation [32,44]. Although difficult to generalize from this preliminary study, the reinvention of the TP system in East Hararghe has led to not only the rapid diffusion, but also the technical sustainability of the new technology. Future studies in East Hararghe may reveal that reinvention on the TP system also plays a key role in scaling up of the new technology.

In East Hararghe, almost all farmers with TP systems have invested in reinvention and created a new irrigation system. Nevertheless, the new system would not have been possible without the introduction of the TP system in the first place and, in particular, without the training of local farmers on excavating boreholes and installing the pump system. However, without the independent experimentation of the trained farmers, the new systems would not have been possible. The local origin of the new technology suggests it will continue to be adopted by farmers until further improvements, which meet the changing needs of farmers, replace it. This has profound implications to adoption and diffusion of agricultural technologies elsewhere. This can be a classic example of capacity building and provision of technology options open enough to empower local communities to shape their own destiny.

4. Conclusions

The breakthrough and the missing link from the existing irrigation schemes in Haramaya Woreda to the pilot project was the introduction of the controlled excavation technique compared to hand excavation before the pilot project. Training local community members on controlled excavation, which is now-wide spread in the project areas, led to innovative modifications of the initial technology and the excavation technique to satisfy existing needs of the farmers. The opportunity for trained farmers to experiment independently, and develop new tools locally, was key for developing solutions tailored to the local needs. The major impact of the new technology is that it made irrigation accessible to a large number of households and enabled many farmers to accumulate enough resources to diversify their livelihoods into off-farm activities. It is not, therefore, surprising to see the rapid diffusion of the new technology. A more detail study is necessary to gain more insights into the nuances of this successful case of technology introduction, reinvention (innovative modification) and diffusion for possible replication in other sites with similar conditions.

Acknowledgments: We gratefully acknowledge financial support from Daugherty Water for Food Global Institute at University of Nebraska-Lincoln and in-kind support of Haromaya University. We thank our partners at Haramaya University, Haramaya Woreda officials, and iDE Ethiopia for their time and commitment. We are also grateful for all the farm households who took their time to respond to our interviews.

Conflicts of Interest: The authors declare no conflict of interest.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 7 May 2018 doi:10.20944/preprints201805.0108.v1

References

1. Taffesse, A., Dorosh, P. and Gemessa, S. Crop Production in Ethiopia: Regional Patterns and Trends. In *Food and agriculture in Ethiopia: Progress and policy challenges*, Dorosh, P. and Rashid, S., Eds.; University of Pennsylvania Press: Philadelphia, PA, **2013**. https://doi.org/10.2499/9780812245295 (Accessed on 23 April 2018)
2. Licker, R., Johnston, M., Foley, J., Barford, C., Kucharik, C., Monfreda, C., and Ramankutty, N. Mind the gap: how do climate and agricultural management explain the 'yield gap' of croplands around the world? Global Ecology and Biogeography **2010**, 19, 769-782.
3. Awulachew, S. B., Yilma, A. D., Loulseged, M., Loiskandl, W., Ayana, M., and Alamirew, T. *Water Resources and Irrigation Development in Ethiopia*. Colombo, Sri Lanka: International Water Management Institute. Working Paper 123, **2007**
4. Chemeda, E. D., Babel, M. S., Gupta, A. D., Seleshi, B. A. and Merrey, D. Farmers' Perception of Water Management under Drought Conditions in the Upper Awash Basin, Ethiopia. *Water Resources Development* **2006,** 22(4), 589-602.
5. World Bank. Ethiopia: Managing water resources to maximize sustainable growth. A World Bank water resources assistance strategy for Ethiopia. The World Bank Agriculture and Rural Development Department. Report No. 36000-ET. Washington, DC, USA, **2006**.
6. Devereux, S. Food insecurity in Ethiopia: A discussion paper for DFID. IDS: Sussex: England; **2000**, pp. 1-18. Available online: https://www.ids.ac.uk/files/FoodSecEthiopia4.pdf (accessed on 25 April 2018).
7. World Food Program and Food and Agriculture Organization of the United nations *The State of Food Insecurity in the World Addressing food insecurity in protracted crises*. Joint Report, Rome, Italy, **2010**.
8. Conway, D. and Schipper, E. Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *Global Environmental Change* **2011**, 21, 227–237.
9. Makombe, G., Kelemework, D. and Aredo, D. A comparative analysis of rainfed and irrigated agricultural production in Ethiopia. *Irrigation and Drainage Systems* **2007**, 21(1), 35-44.
10. MoWIE (Ministry of Water, Irrigation and Energy).*Water Resources of Ethiopia*. The National and International Perspective, Awareness creation Program prepared for Public Relation officials, Addis Ababa, Ethiopia, **2013**.
11. Semu, M. A. Agricultural Use of Ground Water in Ethiopia: Assessment of Potential and Analysis of Economics, Policies, Constraints and Opportunities. *AgWater Solutions Project Case Study* IWMI, **2012**.
12. Mosello, B., Calow, R. Tucker, J., Parker, H., Alamirew, T., Kebede, S., Alemseged, T. and Gudina, A. *Building adaptive water resources management in Ethiopia*. ODI Report, London: ODI, **2015**. Available online: https://www.odi.org/ (accessed 10 February 2018).
13. GTP I. *Growth and Transformation Plan (GTP) 2010/11-2014/15*. Ministry of Finance and Economic Development (MoFED), Addis Abeba, Ethiopia, **2010**.
14. MoWR (Ministry of Water Resources). *Water Resources Management Policy*. Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia, **1998**.
15. MoWR (Ministry of Water Resources). *Irrigation Development Strategy* (Component of the Water Sector Development Strategy). National Planning Commission Draft Report. Addis

Ababa, Ethiopia, **2001**.

16. NPC. *The second growth and transformation plan (GTP II) (2015/16-2019/20)*. National Planning Commission, Ethiopia, **2015**.
17. Burney, J., Naylor, R., and Postel, S. The case for distributed irrigation as a development priority in sub-Saharan Africa. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)* **2013,** 110(31), 12513-12517.
18. Haile, G.G. and Kassa, A. K. Investigation of Precipitation and Temperature Change Projections in Werii Watershed, Tekeze River Basin, Ethiopia; Application of Climate Downscaling Model. *J Earth Sci Clim Change* **2015**, 6, 1-11.
19. Woodhouse, P., Veldwisch, G., Venot, J., Brockington, D., Komakech, H. and Manjichi, A. African farmer-led irrigation development: re-framing agricultural policy and investment? *The Journal of Peasant Studies* 2017, 44(1), 213-233.
20. Awlachew, S.B. and Ayana, M. Performance of irrigation: Assessment at different scales in Ethiopia. *Experimental Agriculture* **2013**, 47(1), 57-69.
21. Dessalegn, M. and Merrey. D. Motor pump revolution in Ethiopia: Promises at a crossroads. *Water Alternatives* 2015, 8(2), 237-57.
22. Beyene, S., Regassa, T., Legesse, B., Mamo, M., Willis, M.S., Tadesse, T., Woldehawariat, Y. Rural livelihoods in drought prone areas of East Hararghe and South Wollo, Ethiopia: Surviving or thriving? *PLOS One* (**Under Review**).
23. Feder, G., and Savastano, S. Modern agricultural technology adoption in sub-saharan Africa: A four-country analysis. In *Agriculture and Rural Development in a Globalizing World: Challenges and Opportunities.* Pingali, P., and Feder, G., Eds.; Routledge Earthscan, New York, NY, **2017**; pp. 11-25; ISBN 9781138231825
24. Jayne, T. S., and Rashid, S. Input subsidy programs in sub-Saharan Africa: A synthesis of recent evidence. *Agricultural Economics* **2013**, 44, 547-562.
25. Moser, C. and Barrett, C. The complex dynamics of smallholder technology adoption: the case of SRI in Madagascar. *Agricultural Economics* **2006**, 35, 373-388.
26. Abebaw, D. and Haile, M. The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia. *Food Policy* **2013**, 38, 82-91.
27. Bandiera, O. and Rasul, I. Social networks and technology adoption in northern Mozambique. *The Economic Journal* **2006**, 116(514), 869-902.
28. Besley, T. and Case, A. Modeling Technology Adoption in Developing Countries. *The American Economic Review* **1993**, 83(2), 396-402.
29. Dercon, S. and Christiaensen, L. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *Journal of Development Economics* **2011**, 96(2), 159-173.
30. Mendola, M. Agricultural technology adoption and poverty reduction: A propensity-score matching analysis for rural Bangladesh. *Food Policy* **2007**, 32(3), 372-393.
31. Neill, S. and Lee, D. Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in Northern Honduras. *Economic Development and Cultural Change* **2001**. 49(4), 793-820.
32. Rogers, E. Diffusion of Innovations, 5th ed.; The Free Press: New York. New York, **2003**.
33. Maertens, A. and Barrett, C. Measuring Social Networks' Effects on Agricultural Technology Adoption. *American Journal of Agricultural Economics*, **2013**, 95(2), 353-359.

34. Kaine, G., and Bewsell, D. Adoption of Integrated Pest Management by apple growers: the role of context. *International Journal of Pest Management* **2008**, 54(3), 255-265.
35. Kebede, Y. Risk behavior and new agricultural technologies: the case of producers in the central highlands of Ethiopia. *Quarterly Journal of International Agriculture* **1992**, 31, 269-284.
36. Simtowe F., Kassie, M. Diagne, A., Silim, S., Muange, E., Asfaw S. and Shiferaw, B. Determinants of Agricultural Technology adoption: the Case of Improved Pigeonpea Varieties in Tanzania. *Quarterly Journal of International Agriculture* **2011**, 50(4), 325-345.
37. Tefera, T., Tesfay, G., Elias, E., Diro, M. and Koomen, I. Drivers for adoption of agricultural technologies and practices in Ethiopia - A study report from 30 woredas in four regions. CASCAPE project report no. NS_DfA_2016_1, Addis Ababa, Ethiopia, **2016.**
38. Pannell D., Marshall G., Barr N., Curtis A., Vanclay F. and Wilkinson R. Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture* **2006**, 46:1407-1424.
39. Central Statistical Agency (CSA). Statistical Oromiya. Central Statistical Agency of Ethiopia, Addis Ababa, Ethiopia, **2007**. http://catalog.ihsn.org/index.php/catalog/3583 (Accessed on 25 March 2018)
40. Alemayehu, T., and Furi, W. and Legesse D. Impact of water overexploitation on highland lakes of eastern Ethiopia. *Environmental Geology* **2007**, 52(1), 147-154.
41. Tadesse, N. and Abdulaziz, M. Water Balance of Haromaya Watershed, Oromiya Region, Eastern Ethiopia. *International Journal of Earth Science and Engineering* **2009**, 2(6), 484-498.
42. Setegn S, Chowdary VM, Mal BC, Yohannes F, Kono Y. Water Balance Study and Irrigation Strategies for Sustainable Management of a Tropical Ethiopian Lake: A Case Study of Lake Alemaya. *Water Resources Management* **2011**, 25(9), 2081-2107.
43. Senti, E., Tufa, B, and Gebrehiwot, K. Soil erosion, sediment yield and conservation practices assessment on Lake Haramaya Catchment. *World Journal of Agricultural Sciences* **2014**, 2(7), 186-193.
44. Ansari, S., Fiss, P. and Zajac, E. Made to Fit: How Practices Vary as They Diffuse. *Academy of Management Review* **2010**, 35(1), 67-92.