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Article

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

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Abstract: In 2013, thirty-eight treadle pumps (TPs) were installed as low-cost technology introduction for small-scale irrigation in eastern Ethiopia. This pilot project also trained six farmers on tube well excavation, as well as the installation and maintenance of pumps. In June 2015, researchers visited nine of the thirty-eight TP villages and found only two TPs functioning as originally installed. The rest were replaced with a new technology developed by the trained farmers. Farmers, empowered by training, gained more control in developing technology options tailored to local needs and conditions of their communities. Adopters of 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 technology had 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, local ownership of the new technology, including skills used in well drilling and manufacturing excavation implements, made the modified irrigation technology affordable and accessible to the majority of households. Third, this innovation spread organically without any external support, confirming its sustainability.

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

1. Introduction

In Ethiopia, more than 80% of the population lives in rural areas with agriculture representing the primary source of their livelihoods [1]. The majority of agricultural production is based on traditional smallholder farmers, who cultivate over 90% of the total arable land in the country [2]. Thus, agricultural development 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 the potential and the actual agricultural production in Ethiopia [3]. Almost all smallholder farming in Ethiopia is rain-fed [1]. 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 as a whole [5]. Given the rapid population growth and low output of traditional 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], which is likely to negatively affect rain-fed agriculture. Paradoxically, the highlands of Ethiopia receive very high amounts of rainfall, with annual runoff volume of up to 122 billion m³ of water from 12 major river basins [1]. 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 institutions, and poor implementation of water use and management policies in Ethiopia have limited the 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 being 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 the livelihoods of rural households and facilitating adaptation to climate change [17]. As rural households constitute the majority of the population [17], a significant effort is being made by the Ethiopian government and its development partners to expand irrigated agriculture, including small-scale irrigation [18].

Similar to other parts of sub-Saharan Africa [19], data on small-scale irrigation in Ethiopia is very limited [9,20]. It is estimated that the current irrigated area covers only about 7% of the total estimated 5 million hectares considered suitable for irrigation [11,20]. More detailed reviews on the status, trends, challenges, and potentials of small-scale irrigation can be found in studies by Haile and Kasa [20] and Hagos et al. [21]. 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, and treadle and powered pumps to irrigate their crops [18,22]. Because of the enhanced productivity, relative to rain-fed farming, governmental and non-governmental development actors have invested considerable efforts and resources to support the adoption of irrigation by smallholder farmers [18], with some positive results in both rural poverty reduction and improved technology adoption [23,24]. However, many researchers have observed that the uptake rate of improved agricultural technology is lower than expected primarily due to the top-down approach of agricultural development in general and implementation of extension services in particular [25,26].

In order to improve the relationships between farmers and researchers, we designed an empowering approach through participatory action research, which developed pilot projects, based on community-stated needs, and assessed the performance of these pilot projects for lessons learnt for improvement, scaling, and sustainability within the context of our study area. The contribution of this article is in the approach taken to introduce the technology: from need assessment and technology introduction to capacity building, which enables local experimentation or 'trialability' [27] that enhances local innovation.

In 2010, we developed a long-term collaborative research program, "Farming, Food, and Fitness" (3F), which aimed to develop strategies to enhance agricultural productivity, improve dietary practices, and measure the efficacy of these strategies through participatory action research in two of the most drought-prone regions in Ethiopia. Baseline information collected in 2010 and 2011 revealed high demand for access to irrigation among study households. In order to address this high demand through a pilot project, the 3F research program sponsored International Development Enterprise (iDE) Ethiopia to install 38 treadle pumps (TPs) in 2013. This report presents the result of a preliminary assessment of this pilot project. The objectives of the preliminary assessment were to assess outcomes of the pilot project in general and the status of TPs installed by iDE in particular from the farmers' perspectives. The preliminary assessment had the following research questions. What were the status

and outcomes of the TPs installed by the pilot project? What were the benefits and limitations of the TPs? Why did farmers switched to the new technology? What were the contributing factors for the diffusion of the new technology?

2. Approach and Methods

2.1. Approach

This preliminary assessment and the pilot project were part of the long-term multi-disciplinary, collaborative research program, 3F, involving three universities: University of Nebraska-Lincoln in the USA, and Haramaya and Wollo Universities, both in Ethiopia. The partners are engaged in a participatory approach to address agricultural productivity, food security, and nutrition in two drought-prone areas: South Wollo and East Hararghe in Ethiopia (see Figure 1). In 2010, a project launching workshop was hosted by each of the two universities in Ethiopia, where stakeholders, including relevant government departments, non-governmental organizations (NGOs), and researchers from each of the aforementioned areas came together to discuss the research program and potential areas of focus. Following the launching workshop, qualitative fieldwork was conducted to learn about farmers' aspirations, needs, and challenges. Based on stakeholders' feedback, questionnaires were developed for an extensive quantitative surveys conducted in 2011 in order to provide baseline information for the 3F program. Farmers ranked water shortage as the primary limiting factor for agricultural production and food security. Farmers stressed access to irrigation as the highest need to mitigate the impact of drought, which is becoming increasingly frequent. Therefore, our first pilot project focused on small-scale irrigation. We collaborated with International Development Enterprise (iDE) Ethiopia, who carried out groundwater assessment in 2012 and 2013 to identify areas suitable for installing TPs for low-cost Household Irrigation Technologies (HITs).

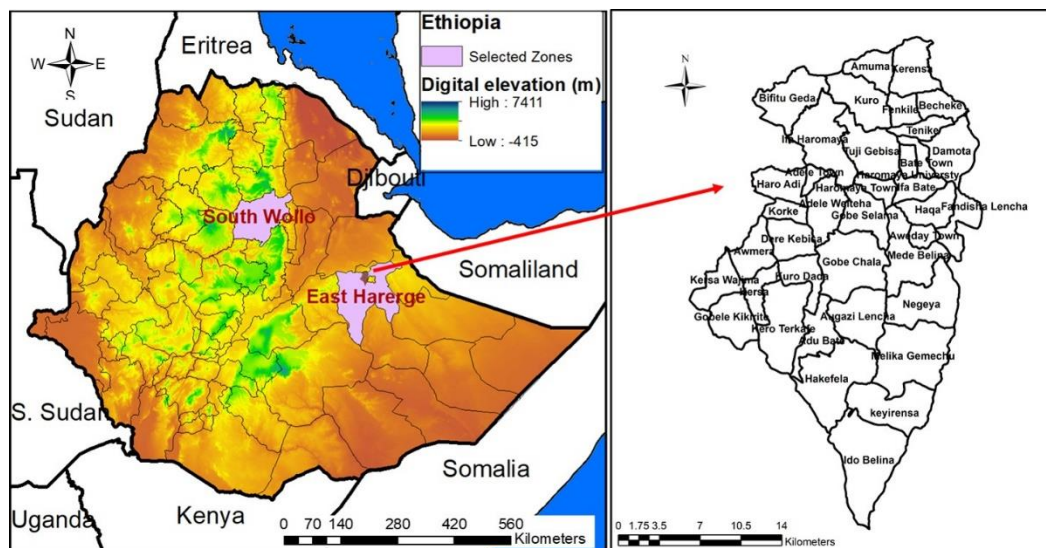


Figure 1. Map of Ethiopia showing the study areas.

Between February and June 2013, fifty-five wells were drilled in five *kebeles* (sub-districts) of Haramaya *Woreda* (district) in East Hararghe as a pilot project to provide HITs (Figure 1). Out of the 55 wells drilled during the pilot project, 38 wells were successful, with sufficient water at appropriate depth for manual pumps. The remaining 17 wells were unsuitable due to stone impediment, insufficient and/or absence of a permeable layer, and static water level being too deep for manual pumping. This 70% success rate is considered good compared to drilling success rates in other parts of Ethiopia [28].

During the pilot project, the area irrigation branch of the ministry of agriculture, in collaboration with Haramaya University and iDE Ethiopia, trained six individuals in drilling boreholes and installing casings, hoses, and pumps. Although the training mainly focused on manual well drilling, it also included skills on well casing installation, maintenance of wells, as well as the installation and maintenance of pumps. The trainees, hired as daily laborers during the pilot project, participated in excavating and installing TPs and quickly attained the skills required to maintain the wells and service the equipment for proper function. The TP technology, although very low in capacity, was an improvement over some of the preexisting farmers' irrigation practices in the study. The pilot project assumption was that TPs, in addition to being low-cost HITs, would also minimize the dependency of local farmers on harvesting water in big and open hand-dug wells, with diameters of up to 20 m (Figure 2). These wells created large soil disturbances and required costly cleaning, using both human labor and excavators when the water level dropped during the dry season, to remove accumulated sediment. Moreover, these open wells pose perpetual danger to human and livestock.



Figure 2. Traditional irrigation water extraction (Farming, Food, and Fitness (3F Photo Archive)).

After the completion of the pilot project, these trainees, in collaboration with local artisans, were able to locally manufacture 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. Using the most influential theories in agricultural technology adoption, the theory of 'diffusion of innovations' by Everett Rogers [27], this report investigates the adoption and subsequent fate of the TPs introduced during the pilot project and the diffusion of the new technology in East Hararghe, Ethiopia. This theory explains not only how innovations are adopted and spread through a population but also how they are modified during implementation, thus providing an appropriate framework for interpretation of the preliminary assessment findings in this report.

2.2. Study Areas

Haramaya *Woreda* (district) is located in East Hararghe Zone of Oromia Regional State (Figure 1). The capital town, Haramaya, is located about 500 km from Addis Ababa. Haramaya *Woreda* has thirty-three rural and two urban *kebeles* (sub-districts) with a total population of 220,986 [29]. 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 [30]. 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 [31]. Although endowed with high underground water, the *woreda* is characterized by frequent drought, crop failure, severe land degradation, and increasing vulnerability to chronic food insecurity.

In Haramaya *Woreda*, Lake Haramaya and shallow ground water (6 to 30 m deep) in the dry lakebed and catchments provided the opportunity to access irrigation for the households that could afford the irrigation infrastructure [32]. Deep wells, open pits, and ponds were used to access the underground water for irrigation (Figure 2). The management of these small-scale irrigation schemes also varied; most were privately owned but large ponds were shared by multiple households. Farmers used furrow and flood irrigation by pumping the water directly to the fields using large hoses, often using motorized pumps. Alternatively, farmers pumped water to a reservoir (3000 to 10,000 m³) first and then distributed the water from the reservoir to fields (Figure 3). Sometimes, they also had a series of reservoirs and pumps that could take the water more than half a kilometer away from the original source.

Irrigation is primarily used for vegetable and high-value cash crops in Haramaya. The major vegetable crops include onion, potato, tomato, carrot, beets, various leafy greens, and khat, a perennial shrub produced for its stimulant leaf and soft buds [33]. 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 [33].



Figure 3. Pumping water out of temporary reservoir to irrigate a vegetable farm. Plastic membrane reduces seepage (3F Photo Archive).

2.3. Data Collection Methods

Qualitative data was collected using focus group discussions, key informant interviews, and field observations. Before the actual interviews were made, enumerators obtained informed consent from

participants. The University of Nebraska Institutional Review Board reviewed and approved the study protocol and all supporting documents (IRB Approval #: 20100710992EP).

2.3.1. Focus-Group Discussion

Focus-group discussions (FGDs) were conducted with farmers from eight different villages in Haramaya where the TPs were installed. The size of each group differed from village to village, ranging from three to nine farmers of mixed gender, as determined by the number of people available in the proximity of their farm plots at the time of the research visit. Points of discussions covered a wide variety of issues but focused on farmers' perceptions of TP irrigation experience and impacts (both negative and positive) of TP irrigation. Included in the discussion were topics such as cropping patterns, use of inputs (seeds, fertilizers, pesticides), as well as concerns and challenges related to irrigation practices and institutions related to water use and management. Also included were questions related to why farmers switched to the new technology, whether or not there were households who abandoned the TP without switching to the new technology, and if so, why they made their decision.

2.3.2. Key Informant Interview

Key Informant Interviews (KIIs) were held with government officials (4), development agents (2), local well drillers (2), technical experts (1), researchers (2), university officials (4), and local elders (4). The KIIs included semi-structured interviews covering a wide variety of topics, depending on the interviewee's institutional affiliation. It included topics on aggregate data regarding irrigation, policies and practices related to irrigation development, institutional support to farmers, as well as market-related and natural resource management issues.

2.3.3. Field Observation

During farm visits, observations were made on the status of the irrigation schemes (i.e., if they were currently functional or not). One of the TP owners demonstrated to us how it worked (Figure 4). Similarly, one of the trained farmers demonstrated how the new technology worked. We also visited storage facilities for equipment used for installation of the new system, hoses used to convey water to the fields, and fuel-powered generators used to pump water. We also recorded major crop types grown on irrigated fields, cropping patterns (strip or intercropping), cropping cycles (from interviewing farmers), irrigation methods used (flood, furrow, or other), climatic impacts (frost-damaged plants), plant pests and disease pressures, and use of TP systems and the new technology.

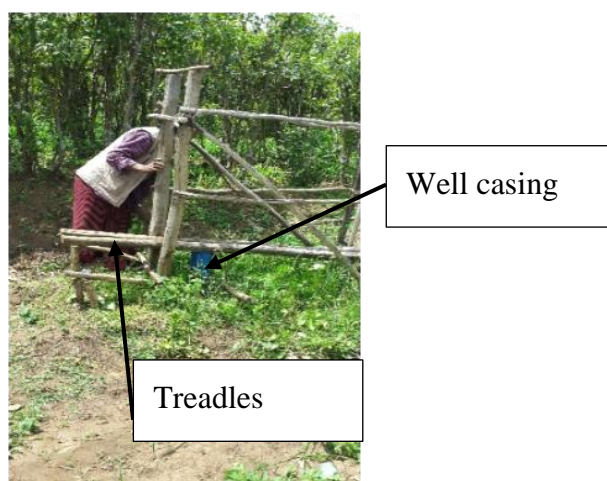


Figure 4. Still functional treadle pump (3F Photo Archive).

3. Results and Discussion

3.1. Farmers' Perception of Irrigation

The majority of farmers in the focus group discussions were enthusiastic about access to irrigation. Farmers who have access to irrigation explained the benefits, but also the challenges, of access to irrigation. Among the benefits, farmers explained that they were able to cultivate at least two times a year, which would have been often impossible without irrigation. In addition, they stated that irrigation enabled them to produce high-value crops for the market. This enabled them to generate income to meet some of their financial needs, such as finances needed to cover their children's education, health care services, and improved homes. The income generated from TP irrigation, for example, paid for the new technology. The most important outcome in all focus group discussions was that access to irrigation minimized the impacts of drought. They also indicated that access to irrigation improved the wellbeing of not only the households who have access to irrigation but also communities at large due to the social support system of relatives and friends.

Farmers that practiced irrigation for at least two cropping cycles mentioned improved production and increased income. The challenges farmers faced included not realizing the full potential of irrigation agriculture due to limited access to improved seeds and other inputs, price fluctuations for their crops, and plant pests and diseases. Despite these challenges, which sometimes caused economic losses, farmers claimed that irrigation agriculture significantly outperformed rain-fed agriculture.

3.2. Farmers' Innovation in East Hararghe

Most of the TPs installed in 2013 had been partially (as supplement to the new system) 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 could be irrigated with the TP was at most 50 by 50 m, which was too small for most farmers' needs, especially when they needed to expand irrigated fields.
2. High demand for labor: Farmers explained that the manual operation of the TP required high labor input for the small amount of water output. The new system can be mounted with fuel-powered pumps.

For these two reasons, among the nine TP sites observed during the preliminary assessment, only two were still functional. 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 m away. The second, owned by an elderly farmer, was the only TP still in use as a sole source for household irrigation (Figure 4). During the preliminary assessment, this farmer was planning to switch to the new technology. One of the female farmers who recently moved to the new technology acknowledged the significant impact of the TP. She stated, "the TP 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.

3.3. Local "Reinvention": The New Technology

During the pilot project, one of the interventions included training selected community members on the construction and maintenance of TP systems. The training aimed to build local capacity for maintaining installed TP systems or for installing new TPs if the demand would arise. Although the local demand for access to irrigation was high and the drilling skills acquired by trained farmers was expected to be high, the assumption was that the conventional TPs would spread widely. However, the demand was more for the higher capacity system than what the conventional TPs could provide. The newly trained individuals were able to meet this demand through local innovation. This local innovation had four main components: locally manufactured efficient excavation tools, wider diameter boreholes, effective casing, and installing motorized pumps. The latter three are the direct result of

training by the pilot project. However, the first, although inspired by the auger used in the pilot project, was an improved version in regard to both its diameter and excavating efficiency due to its serrated edges.

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 blacksmith, were able to design a more efficient auger with different diameters and serrated edges. These augers, developed locally, were used to excavate wider (Table 1) boreholes to provide a larger volume of water than the conventional TP system could provide, meeting farmer's demands for higher water volume per unit time.

Table 1. Comparison among irrigation technologies in the study area.

Attributes	Traditional Pit	Traditional Borehole	Treadle Pump	Modified (New) Technology
Size (diameter)	Variable	About 1 m	4 cm	13 cm
Equipment	Long-handled hoe, Excavator	Long-handled hoe	Auger	Auger (locally made)
Excavation method	Manual, Machine	Manual	Manual	Manual
Capital	4000 to 8000 US dollar (USD)	Unknown	Not applicable	250 to 400 USD
Maintenance	Variable	Unknown	Unknown	Unknown
Irrigation capacity	Variable but sufficient	Sufficient	Insufficient	Sufficient
Water extraction	Motorized pump	Motorized pump	Manual pump	Motorized pump

Wider diameter of borehole: One of the limitations of the TP technology is the narrow diameter of the well (Table 1). According to farmers, the TP borehole of 4 cm in diameter was too small to provide enough water to irrigate more than one plot (an average household plot was about 0.2 ha and households typically have multiple plots). The farmers trained during the pilot project were now able to excavate wells with a diameter of 13 cm (Table 1), 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 less than one hectare. The wide use of underground water raised issues among communities. Farmers revealed their concerns for underground water depletion due to increased extracting of water for irrigation and other purposes. However, they also indicated hope in regard to the recent watershed management efforts and the signs indicating recovery of the dried Lake Haramaya.

Cost-effective casing: One of the major constraints for traditional methods of accessing underground water for irrigation in Haramaya *Woreda* was the collapsing of well walls, due to the common nitisol soil in Haramaya [34] that easily fall apart. The high diameter of the open pits wells in the *woreda* minimized wall collapse (Figure 2), but it still required significant maintenance costs, after each rainy season. The trained farmers were able to innovate using cost-effective, plastic casing for the new system to function properly. From the farmers' perspective, the new excavation techniques also eliminated the need for laborers to be at the bottom of the well during excavation (Figure 5).

Between the end of the pilot project in June 2013 and the preliminary assessment in June 2015, community members trained during the pilot project constructed more than 100 new systems. Furthermore, the new system cost 250 to 400 USD Farmers used to pay more than 1000 USD for the excavation of traditional water pits (as in Figure 2). One particularly large water pit, shared by 21 individuals, cost nearly 2000 USD (Table 1). Traditional water pits were not only expensive to construct and maintain, as the walls cave in frequently, but also required more land that could otherwise be used for cultivation.

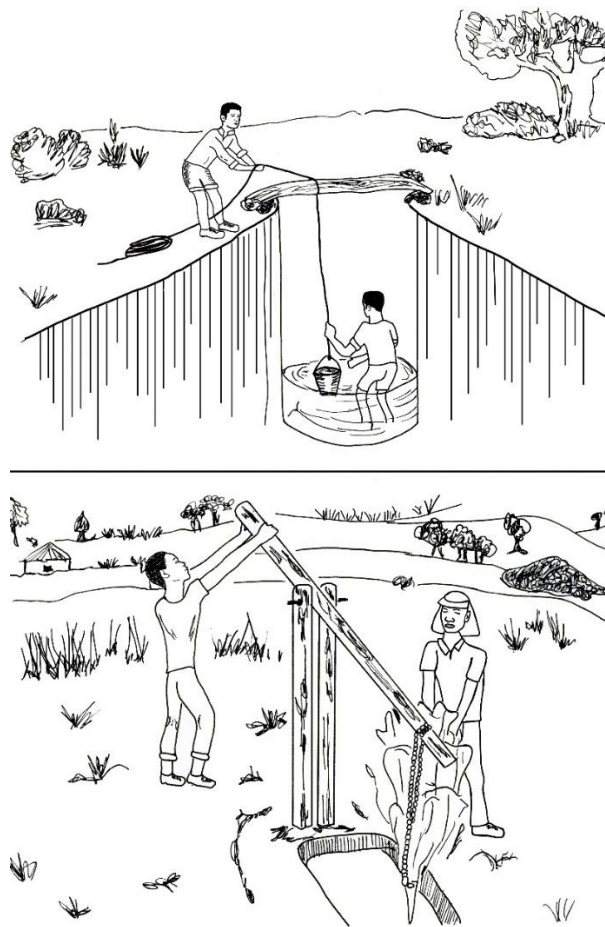


Figure 5. Well excavation: traditional method (top) and new excavation method (bottom). (Courtesy of Eledon Beyene).

Since the introduction of the TP system, farmers reported doubling crop production. Using the new system, they reported increases in income from an estimated 2000 USD to 4500 USD annually (focus group discussion in Tuji Gebissa, 13 June 2015). According to farmers, the new excavation techniques (Figure 5) could go deeper (up to 30 m), thus making more water available for irrigation (the initial TP excavation could reach a maximum depth of only 20 m). The new systems could support up to 10 households, with an average of six individuals per household. This, according to the farmers interviewed, was 10 times more than the original TP system. Building the capacity of selected farmers empowered local communities and individuals to think and act in their own interests and to develop irrigation technologies that met their needs and conditions without the support or direction of external bodies. This confirmed the sustainability of the innovation.

It may be instructive to see our preliminary observation through the framework of Rogers' diffusion of innovation theory [27], 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 as well as the traditional pit well irrigation system. Second, the technology is consistent with the values, experiences, and needs of the farmers in Haramaya Woreda, where about 60% households were engaged in some form of irrigation prior to the pilot project. Third, the unique aspect of the new technology in Haramaya is that it was a local innovation, which makes the 'complexity attribute' [27] negligible. 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 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 the observability of the results to distant farmers. Moreover, the proximity of the study *kebeles* to Haramaya University and *Woreda* Extension Office, two entities that have an interest in associating with the farmers’ success stories, could have helped.

Another insightful contribution by Rogers [27] 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 a faster rate of adoption, as reinvention makes the innovation fit to a broad range of adopters’ conditions [27]. As reinventions enhance the fit between an innovation and adopters’ needs, they are likely to lead to the continued use of the innovation and hence to the sustainability of the innovation [27,33]. Although difficult to generalize from this preliminary study, the reinvention of the TP system in Haramaya has led to not only the rapid diffusion but also the sustainability of this local innovation. Future studies in Haramaya may reveal that the reinvention of 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 the 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 tube wells and installing pump systems. However, without the independent experimentation of the trained farmers (empowerment), the new systems would not have been possible. The local origin of the new technology suggests that it will continue to be adopted by farmers until further improvements that meet the changing needs of farmers replace it. The local control of this technology suggests that it will continue to be sustainable. This has profound implications for the 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 destinies.

4. Conclusions

Trained farmers, empowered to experiment independently, developed new tools and came up with sustainable solutions tailored to the local needs. The breakthrough and missing link from the traditional irrigation schemes in Haramaya *Woreda* to the pilot project was the introduction of the controlled excavation technique. Compared to the traditional hand excavation, the new excavation technique was more efficient in reducing cost, labor, and the land area needed for the construction of the system, which enhanced its comparative advantage. The introduction of controlled excavation, now widespread in the study areas, led to innovative modifications of the initial TP technology to satisfy the needs and aspirations of the farmers. The major impact of the new technology was that it made irrigation affordable and 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 have seen the rapid diffusion of the new technology. Local capacity for installing and maintaining the whole irrigation structure and for fabricating tube well excavating tools ensures the sustainability of the innovation. Designing the pilot project based on farmers’ stated needs, building the capacity of farmers to maintain or modified the technology, and farmers’ ability to independently experiment on the technology were crucial factors for the adoption and diffusion of the new technology. However, a more detailed, systematic study is necessary in order 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.

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