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Diffusion of an evaporative cooler innovation among smallholder dairy farmers of Western Uganda

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A B S T R A C T

In many sub-Saharan countries' dairy industries, the evening milk is either wasted or processed into low-value products because it is highly perishable and cannot be kept fresh until the next morning, when it is safe to travel (no access to electricity and night travel is unsafe). To save this milk, a "bottom of the economic pyramid" solution in a low capacity (15.5 L), evaporative cooler has been developed and its performance has been assessed while initiating its diffusion among smallholder dairy farmers of Western Uganda. The cooler successfully preserved the milk over 24 h period with acceptable quality in terms of the Resazurin test scale. Although the rate of the cooler innovation diffusion was found consistent with other diffusion studies in rural settings, interviews of participants suggested that a larger capacity cooler (50–100 L) and on-farm regeneration with biogas will accelerate the diffusion rate, affirming that at the micro-level, societal shaping of technology is indispensable to successful diffusion.

1. Introduction

1.1. The evening milk problem

Uganda is a sub-Saharan country with an estimated population of 30.7 millions, of which 85.2% live in rural areas [1] where their livelihood is derived from farming – growing crops and rearing animals. The majority fit the definition of smallholder farmers – defined by Herrero et al. [2] as those farmers with mostly less than 2 ha of land, several crops, and perhaps a cow or two, including herders (most with fewer than five large animals), and predominantly found in Africa and Asia. It is estimated that, of Uganda's total population, 68.7% are employed by the agricultural sector [1,3], which contributes 15.1% of the country's total GDP and about 90% of total exports [3–5]. The agriculture sector contribution to the country's GDP has declined over the years (e.g., from 36.3% to 15.1% between fiscal years 2004/05 and 2008/09's) [6] and is posting a growth rate of about 1.5% [7]. Contrasting this growth rate with a population growth rate of 3.2% [8,9], suggests a looming severe food insecurity. As such, the Government and the development community at large are targeting increasing food production, especially on smallholder farms, that are contributing the bulk of the country's food supply [9,10]. For example, the East African Dairy Development vision is to move smallholder farmers out of poverty by delivering farmer-focused, value-chain activities so as to stimulate dairy farm production.

The livestock sub-sector has responded favorably to development programs. For example, the total number of households rearing cattle has increased from 1.2 [11,12] to over 2.5 million between 2005 and 2009 [10,13]. Currently, the total number of cattle is estimated at 11.4 millions [14–

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16]. As a result, milk production has showed rapid growth, from 700 million liters in 2000 to over 1.9 billion liters [9,11], based on 2010 predictions (Fig. 1). There is capacity for further growth. Currently, the country exports an estimated 2% of milk production to the regional markets but this excludes significant, yet un-quantified, informal cross border trade in raw milk. It is also anticipated that if production is boosted in Uganda, it could substantially increase the country's revenue through meeting the milk deficit in its neighboring countries of Kenya, Democratic republic of Congo, Sudan, Tanzania and Rwanda [9].

Despite the great attention milk production is receiving, the postharvest losses have been estimated at about 23 million U.S dollars [9,17]. The highest losses have been identified to be at the farm level (accounting for 5.8%) and during transportation (11%) [14,18]. These losses are directly incurred by the smallholder dairy farmers. Numerous factors are behind these losses, key examples include poor road network, insufficient labor, and lack of electricity. During the rainy season, milk yields tend to increase [9,19], as feeder roads to collection centers with large (3000–5000 L) electric coolers, typically located in trading centers deteriorate; transportation of the evening milk (in the dark) becomes extremely unsafe. The problem is even aggravated by the stiff competition for market share during this period. Because milk production is high in the rainy season, the capacity of most collection center coolers is fast exceeded [9]. This forces the centers to reject all milk in excess of the cooler capacities; the most affected farmers are those who cannot transport their milk quickly enough, and these are the ones living far from the collection centers. In absence of on-farm cooling capacity, milk either spoils or is processed into low-value products like ghee. Additionally, even the morning milk that can make it into the cold chain, when not cooled immediately after harvesting, leads to poor quality [20]. Conventional on-farm cooling requires electricity supply, but the electricity grid distribution in rural areas stands at a mere 2%; woody biomass is the predominant source of energy in the rural areas [1,21]. But cooling technology relying on woody biomass has not been developed as far as the authors can tell.

A means to cool milk on smallholder farms soon after harvesting constitutes a potent change agent with respect to milk quality and quantity improvements, not only in Uganda but in many sub-Saharan countries that share the same milk production and distribution modality. Cooling milk to 4 °C within 4 h of milking meets internationally accepted milk quality standards and saving the evening milk increases the amount of milk that enters the cold chain.

1.2. The evening milk solution – adsorption evaporative cooler

The zeolite adsorption evaporative cooling technology has been adapted in the development of a cooler (560 mm high and 380 mm in diameter with a 15.5 L capacity) [22]. The cooling mechanism is based on zeolite, an alumino-silicate that adsorbs water vapor (refrigerant), a result of heat of vaporization extraction from milk when vaporized under vacuum at room temperature. At the end of the batch cooling cycle, initiated by manually lowering the pressure in the refrigerant (water) chamber via a simple switch, the zeolite is almost saturated with water, and for the cooler to cool again, the zeolite has to be dried (regenerated) by heating the whole cooler at a suitable temperature. In European markets, where this technology is used for cooling beer, centrally located large electric heaters or natural gas ovens are used for regeneration. On smallholder farm level, a biogas-fired oven (biogas regenerator) has been

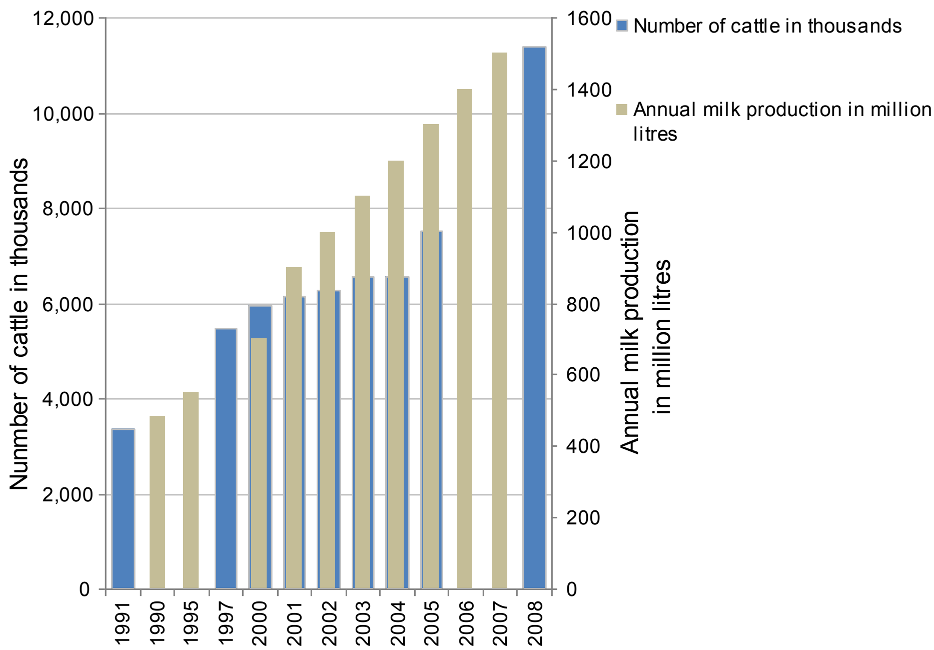

Fig. 1. The trend of the cattle herd and annual milk production in Uganda.

developed. With this system, a smallholder farmer can cool the evening milk overnight or for 24 h, and transport it the following day together with the morning milk, or can cool all the milk as soon as it's produced at the farm and transport it to the market when conditions are favorable, and then regenerate the cooler using a heat source like biogas regenerator. Fig. 2 shows the cooler and brick biogas regenerator.

1.3. Theoretical considerations

Technology and society studies have been dominated by two views on the opposite ends of the axis. At one end the argument presented is that technology shapes society, while at the other end, the argument presented is that society shapes technology [23,24]. While this debate may be highly relevant at the macro-level in developed economies, it seems distant in developing economies, among scientists and engineers, especially at the development and technology nexus. The prevailing view is that technology informs society and society informs technology; it is this "dance", if properly choreographed, that results in technological innovations that are inspiring questions like, "can science and technology end global poverty?" [25,26]. This work is a segment in the "long dance" to deploy off-grid technology toward eradicating poverty.

The objective of this study was two-pronged. First, to assess the performance and acceptability of the cooler under the real target field conditions and second, to initiate the diffusion of the cooler technology among smallholder dairy farmers of Western Uganda. This study reports successful performance of the cooler, with respect to bringing the evening milk into the cold chain, and discusses the challenges experienced with regard to initiating the technology diffusion. Ways of meeting the challenges are suggested.

Fig. 2. Researchers perform a cooler regeneration experiment using biogas produced by a "bubble" digester fed by 5 zero-grazed cows. The cooler is the stainless steel vessel with a black cap the mild steel plate on top of the regenerator is removed and the cooler placed inside the double walled brick structure. The cooler is heated from the bottom through a burner. During regeneration, a layer of bricks is placed on top of the mild steel plate for insulation purposes. The ratio of the mild steel plate exhaust hole to the air inlet opening in front of the regenerator is a key design parameter in achieving a desirable temperature inside the regenerator.

2. Materials and methods

2.1. Study site and community

The study location is shown in Fig. 3, comprised of three sub-counties of Rubindi, Kashari, and Kagongi. The three sub-counties are among the twenty that make up the larger Mbarara district (1846.4 km^2 of land), located in the southwestern part of Uganda, approximately 270 km from Uganda's major city (Kampala), with an estimated population of 457,800. The district is reputable for cattle keeping. Although people have reared traditional Ankole cows in the past years, the recent years have seen the trend shift to rearing crossed and/or pure exotic breeds, resulting in the district being one of the top milk production producers in the country [11,12]. Of the 98 milk collection centers in Uganda, 60% are located in this southwestern region [9,13]. Based on these reasons the district was considered most ideal for the study. The three sub-counties were chosen because they have the largest number of smallholders whose evening milk production at the time was consistent with the capacity of the cooler. Additionally, they all belonged to a single organization, the *Ru*bindi–*Ka*shari–*Ka*gongi (RUKAKA) dairy farmer's cooperative society (RUKAKA hereafter).

The RUKAKA main milk collection center and head offices are located in Rubindi trading centre, which lies 40 km from Mbarara town, along Mbarara–Ibanda–Kamwenge main road. The milk collection business is modeled along an approach that has enabled India to rise to being the World's largest producer of milk within the last fifteen years [9]. RUKAKA is share owned by 446 farmers, and managed by a committee of 12 people, elected by the farmer members. RUKAKA owns three other milk collection centers and employs about ten permanent casual laborers (including truck drivers). The farmers transport milk to the nearest collection centers daily but are only paid in two monthly periods – each period covering fifteen days' milk delivery. Management deducts a certain percentage from every member's milk payment to pay workers, veterinary services, and transport costs incurred in transporting milk from smaller collection centers and to a private milk processing plant in Mbarara town. At the time of writing, RUKAKA had recently opened up two unprocessed milk

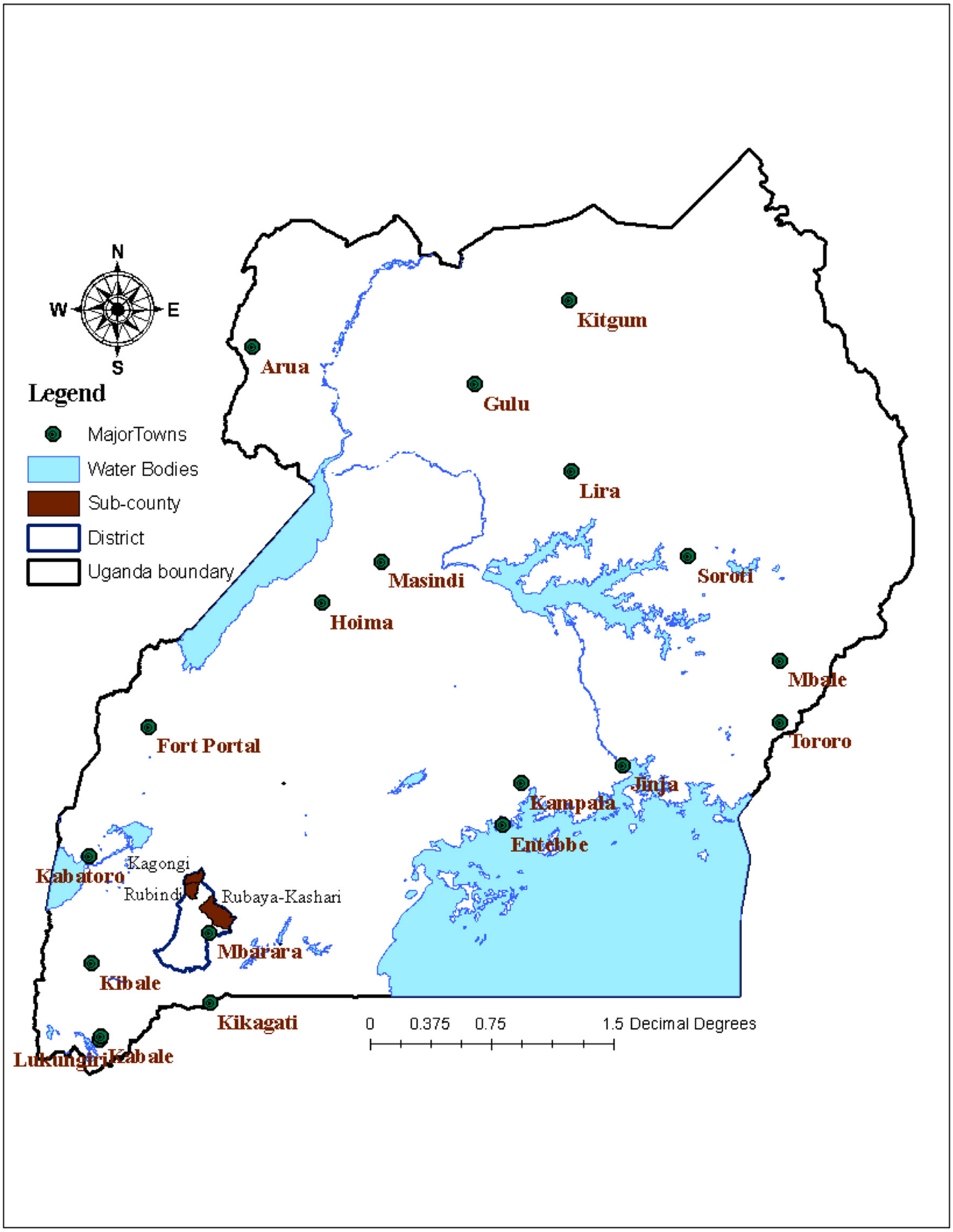

Fig. 3. A map of Uganda showing the location of Mbarara town in relation the sub-counties of in the study site.

sale points in Mbarara town. As a member of the Uganda Crane Creameries Cooperative Union (UCCCU), an umbrella cooperative societies' organization, RUKAKA is participating in the construction of farmer-owned milk processing plant in Mbarara town, to lessen the dependence on the private processor who is allegedly offering below-market prices for the farmers' milk [27]. RUKAKA also owns a savings bank, which streamlines payments and access to credit by its farmer members. Generally, there is only one formal milk supply channel in the three sub-counties – via RUKAKA. The number of farmers who sell their milk elsewhere, e.g., through the informal channel is estimated at less than 20 throughout the three sub-counties.

2.2. Baseline data collection and training material

The instrument used to establish base-line data was developed and administered to farmers identified from RUKAKA milk production records. Approximately 100 farms meet the evening milk production criteria of less or equal to 20 L and a distance from a collection center of at least of 1 km. Two interviewers visited each farm. They were always accompanied by a local community leader and RUKAKA management personnel. This was critical to lend credibility to the project.

Training material was developed with three main learning objectives: First, to sensitize and inform the farmers about the project's background and objectives. Second, to equip the farmers with basic knowledge about the principle of operation of the cooler, cooler maintenance, project work plan and long term benefits. Third, to sensitize and inform the farmers about the benefits of biogas energy option (in comparison to others) for regeneration of coolers and other domestic uses (cooking and lighting). The material was developed for delivery in three separate workshops. To make it easier for participants to attend, the farmers were compensated for the days' income loss due to the fact that they took time away from their farms for the day.

2.3. Diffusion model

"Diffusion" here is defined as the process by which an innovation is sustainably adopted over time among members of a social system, as opposed to the definition in Rogers [28] that emphasizes "innovation communication". The relative speed at which an innovation is adopted by members of a social system is simply measured in terms of number of individuals who adopt in a specified period (e.g., a year). Naturally, most innovators' goal, as they conceptualize a diffusion model, is to maximize the rate of adoption. Given that our innovation is technological or is a tool with hardware and no software attributes, we considered several factors in our diffusion approach as outlined below.

First, adopters were required to pay in kind for the cooler. Why not provide the cooler for free? The literature and experience of development professional at the bottom of the economic pyramid on this question are clear. In rural communities, sale or neglect is usually the ultimate end of freely given technological products [29,30]. This is because, even when prescreening to ascertain need is well done, free things tend to go to the wrong recipients. The fact that a participant is willing to pay or contribute his/her own funds for the product, is the best evidence that ascertains need and determination to make the acquisition profitable. Payment in kind was set at 3 L of the cooled milk for 9 months to "fully pay" for the cooler. The pay-in-kind quantity of milk and pay period were based on average milk prices and a future projected cooler cost when produced in large volumes. Why pay back in kind? As shown in Section 3.1 the smallholders targeted by the project earn 5 dollars or less per day. With this kind of cash flow, it is not possible to have the capital needed to invest in a cooler. The way they typically deal with emergencies that require a large amount of money is to sell one or two cows from their holdings [2,31], a usually "painful" last resort. Also, paying in kind provided some immunity to the farmers against downward milk price changes, while increasing their contribution if the prices fluctuated upwards.

Second, at the start of the first cohort of cooler deployment, the on-farm renewable energy (biogas) regenerator was not ready for deployment; further experimentations were needed to establish conditions for high enough regeneration temperature to achieve satisfactory regeneration. To avoid delays in implementing the study, two electric regenerators were installed at the Rubindi milk collection center (Fig. 4). The coolers were engraved with numbers 01–30 for distribution to fifteen farmers (2 coolers each). Each farmer was required to fill the cooler with the evening milk, turn on the cooler and deliver the milk on bicycle to the nearest collection center the following day together with the morning milk. At the collection center, the milk was tested and if satisfactory, was added to the RUKAKA large cooling tank. The farmer then was issued the second, fully regenerated, cooler for that day's evening milk. After emptying the cooled milk, the first cooler was electrically regenerated and cooled to be ready for next day when the farmer brings in the second cooler. This arrangement eliminated the inconvenience to the farmer of having to wait for his/her cooler to be fully regenerated before returning to the farm. Daily milk receipts from each farmer were recorded and RUKAKA paid the farmers, minus cooler contribution and RUKAKA expenses every 15 days.

The overall diffusion strategy with the first cohort was to incorporate the cooler in the daily milk operation that the farmers are used to and for the farmer to view the cooler as just a can, with the exception that this can was self-cooling.

2.4. Cooler performance assessment

The coolers used in this study, branded "CoolChurn", was fabricated by COOLSYSTEM (Fürth, Germany) – see Kisaalita [22] for more details. Although the "laboratory" performance of the cooler was well established, it was necessary to add cooler performance analysis to the study for RUKAKA management and farmers to see for themselves and for field confirmation of the "laboratory" results. Cooled milk was tested at the RUKAKA collection center with respect to microbial count (using the conventional total plate count – TPC), temperature, and micro-organism biochemical activity (using Resazurin reduction and Lacto-scanning tests). Fresh milk was also tested for comparative purposes. Cooled milk was tested after 24 h in the cooler. Tests were only conducted on two coolers, randomly selected from the 30, to minimize cost and time. Results from the two coolers were considered representative of the cohort.

To perform the tests mentioned above, samples of 1.3 L of fresh and cooled milk (after 24 h in the cooler) were

Fig. 4. A) Rubindi trading center, where the RUKARA milk collection center is located. B) Bicycle transportation of cooled milk in a cooler with handles. C) RUKAKA worker colleting milk delivered by farmers. D) Electric cooler regenerators – two coolers are stacked and are regenerated simultaneously.

obtained. 150 ml were used to determine overall milk quality by the Resazurin test – grades 6 to 4 are acceptable. 100 ml we used to determine the basic milk properties using a Lactoscan Milk Analyzer (New Dairy Engineering and Trading Company – NECTO, Badali, India). Lactoscan measures, temperature, fat, lactose, total solids, nonfat solids, protein, density, freezing point, and water content. Lastly, 1000 ml were used for TPC.

3. Results and discussion

3.1. Profile of RUKAKA smallholder farmers

Visits to 100 farms were attempted, but only 54 visits yielded complete questionnaires. Representative statistics of the 54 farmers are presented in Table 1. In addition to milk, farmers derived income from crop farming (e.g., green bananas). Generally, the RUKAKA dairy smallholders interviewed earned a maximum of 5 dollars per day. They are not alone; half of the world lives on two dollars a day or less, while a billion people live on less than a dollar a day [32]. The farmers' financial situation is further complicated by the large family sizes and/or number of dependants they are responsible for. Although Uganda's average family size is 5 persons per household [1], the figure is higher in rural areas. Family sizes of more than 20 people can be found in rural areas. Although the average rural family size is not known, the interviewed RUKAKA farmers revealed an

Table 1
A summary of characteristics of RUKAKA smallholder farmers.

Attribute	Survey result
Average morning milk produced	38 L
Average evening milk produced	16 L
Average herd per household	25 cattle [min (4), max (80)]
[a]Size of grazing land	Average 28 acres [min (3), max (80)]
System of dairy farming	100% Range
Distance from nearest cooler	Up to 8 miles
[b]Average (max: min) price per liter of milk	(520:150) Uganda shillings
Family size	10 [min (4), max (28)]
Average number of laborers employed	2

[a] Note that most of data on size of grazing land was based on estimates by farmers.
[b] 1 US dollar = 2205 Uganda shillings; Milk market price = 220 shillings per liter.

average of 10 people per household. The family size distribution of the RUKAKA farmers is shown in Fig. 5A.

In most definitions of smallholder farmers, land size is typically 2–5 ha and 2–5 cows [33,34]. On the contrary, RUKAKA smallholders own larger pieces of land and a larger number of animals, as shown in Table 1. Why are they earning less than 5 dollars a day? The simple answer is that they are keeping low-milk yielding cows and since they all practice range grazing, they need large land to produce grass that supports the many cows. They are not using any inputs to increase the productivity of their land. It is evident that they have the capacity to increase their income several-fold, if they can be assisted to properly harness science and sustainable technology in their operations.

Of the farmers interviewed, 74.1% confirmed pouring milk during the rainy seasons either due to lack of ready market, un-conducive weather or absence of laborers to quickly transport milk to the collection center. Bicycles are the only means used to transport milk to the centers. Although all the farmers interviewed owned a cell phone, the network reception in rural RUKAKA is poor. Also, there is no television reception and the road networks leading to the farms are poor. The farmers are connected to the outside world through radio (all farmers sampled owned radios) – implying little access to information. This is aggravated by low level of education for most farmers. The farmers either had no education, or completed primary education (first seven years), or attempted secondary school but were not able to complete for one reason or another (Fig. 5B).

3.2. Profile of project participants

Based on the number of coolers that were available for the entire study (60 units), we needed a total of 30 participants (2 coolers per family). The recruitment of participants was divided into two cohorts; fifteen participants each for the first and second years of the study. Thirty-eight farmers were selected from the 54 that were interviewed. The selection of farmers was based on four major parameters: Need for the cooler as presented by the farmer, distance of the farm from the nearest milk collection centre, amount of evening milk produced at a farm, and contribution of milk business to the farmer's total income. Other questions were used in the establishment of general base-line data.

Generally, farmers whose need for the cooler was within a 6 months period from date of interview, producing 8–20 L of evening milk, with at least 40% of total income derived from milk, and living at least 1 km from the nearest milk collection centre were considered to be most ideal to start the cooler diffusion process with. Farmers with less than 8 L of evening milk and total milk contribution to income below 40%, and those with more than 20 L of evening milk were excluded because the former earned low income from the milk to justify the need to invest in this innovation, while the later could not be served by the 15.5 L capacity.

All the 38 selected farmers were invited to attend the first and subsequent training workshops. However, only 15 farmers showed up. The three sessions were mostly attended by the same farmers. We were curious why the attendance was low. By asking a few who declined our invitation, we learned that some members were discouraged by community leaders who were excluded by the criteria used. These leaders expected to automatically receive free coolers by virtue of their position in the community and for their role in encouraging the smallholders to participate. Other reasons (we suspect surrogate for lack of support from leaders) given were personal commitments and perceiving attendance as a waste of valuable time. It was interesting to find out that the 15 farmers that attended were the most educated of the group (attempted secondary school, but dropped out due to one reason or another). Despite the relatively higher education level, the workshop attendants needed time to grasp the concepts; topics had to be repeated several times, more visuals and hands-on exercises were needed.

3.3. Diffusion of the cooler innovation

Despite the proven performance of the cooler, the diffusion rate of the cooler into society was slower than expected. Of the needed 15 farmers who attended the training workshop, 10 farmers requested coolers, but only

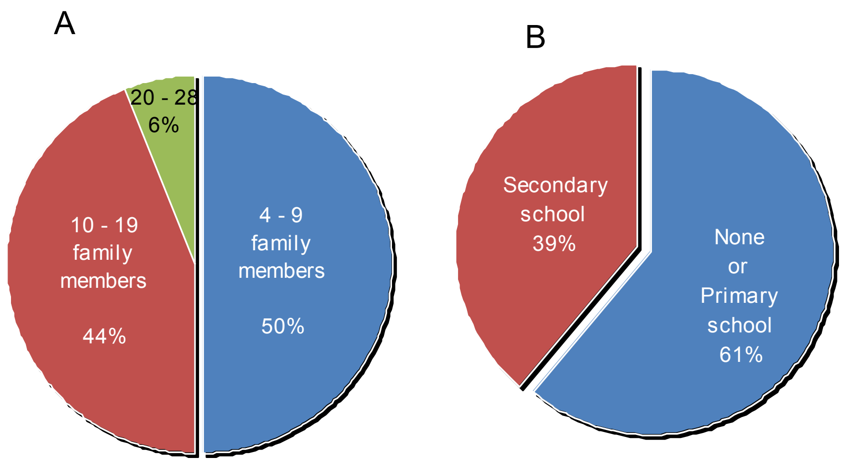

Fig. 5. Family size (A) and education level (B) distribution among RUKAKA smallholder farmers.

6 used the coolers in the months of December (2009), and January (2010). Four farmers just kept the coolers thereafter and did not put them in operation; their response to the question why; was that they were waiting to see how well the project works out. At the time of writing, only two farmers are currently using the coolers. One of the two cools the evening milk and adds the morning milk to the evening milk. The cooler has given this farmer the flexibility when to deliver the milk to the collection center. Because the milk is well preserved for 24 h, the farmer delivers when transportation in conveniently available, e.g., by one of the family members after working in the field.

Initially the cooler had no handles yet was very heavy – weighing about 22 kg when empty – which made it difficult to handle and/or transport on a bicycle, especially when full of milk. Modifications were made to include handles as shown in Fig. 4B. But this did not result in more adoptions. It is possible that it was too late for farmers whose adoption decision hinged on weight to change their minds. The weight problem was exasperated by the long distances from the farms to the collection centers.

To compare the experience in this study to other innovation diffusion studies at the bottom of the economic pyramid, we turned to the classical work on this subject [28], which categorized adopters on the basis of innovativeness as shown in Table 2. It was interesting to observe that the 38 farmers invited to the training workshops mapped reasonably well to the categories in Table 2. Two innovators (5.3%), four early adopters – took the coolers but adopted a wait and see attitude (10.5%). The total of percentage of the top two comes to 15.8, which compares well to the 16% in Table 2. As the characteristics of the top two categories suggest, these adopters are more likely to be the most educated in the community. We looked deeper into the education connection by analyzing the education level of the RUKAKA farmers.

Fig. 5B shows the education distribution of the RUKAKA smallholders. A large percentage is either uneducated or have acquired little education; most of the farmers are primary school drop-outs. Additionally, living in a rural area where they have little access to modern technologies and competitive markets is likely to land them in the late majority or laggard innovativeness categories. In conceptualizing the cooler innovation, the most need was the farmers with the small amounts of milk. These are the farmers for whom; the difference the cooler makes in income is most substantial. Education level (a surrogate for innovativeness) was not considered in the thinking at the time. However, it is no doubt a major factor in the low diffusion level experienced in the first year of the project. This situation has created the cooler capacity-innovation diffusion conundrum; the most educated farmers tend to have large farms and more milk, more than the cooler capacity, yet they are the most likely to belong to the early adopters category and because of their "highest degree of opinion leadership", are most likely to influence the segment of the population that need the small cooler capacity that they will not adopt till the early adopters do. Therefore to diffuse the 15.5-L coolers calls for developing a larger capacity cooler built on the same principles (zeolite adsorption evaporative cooling) that are consistent with the milk production capacity of the educated farmers, estimated between 50 and 100 L.

3.4. *Cooler performance*

In the total plate count, used to assess effect of cooling milk for 24 h in the cooler on milk aerobic content, the number of colonies per ml (N) was only computed when the count fell in the colony range of 25–250 as required in the conventional method. Results showed that cooling reduced N as expected; the fresh and cooled milk Ns ranged between 13,000 and 140,000 and 5900–29,000 respectively. Temperature tests gave an average temperature drop of 18 °C (Fig. 6). A more meaningful assessment of milk quality – the Resazurin reduction test – showed that in all cases milk was either excellent (blue – no color change – grade 6) or very good (light blue – grade 5). To date, all milk cooled in the coolers have passed quality measures and have been added to the rest of the milk cooled at RUKAKA milk collection center. Therefore the cooler is successful in adding the cooled milk to the cold chain under target field conditions.

3.5. *Way forward*

To succeed in the diffusion of the zeolite adsorption cooler innovation at the low capacity level will require two related changes in project direction. First, the development

Table 2
Innovation adopter categorization and characterization [30].[a]

Category	% Among rural social systems	Characteristics
Innovators	2.5	*Venturesome*: Control of substantial financial resources, ability to understand and apply complex technical knowledge, able to cope with a degree of uncertainty, willing to accept an occasional setback.
Early adopters	13.5	*Respect*: More integrated in the social system than innovators, have the highest degree of opinion leadership in most systems, potential adopters look to early adopters for advice and information about innovation.
Early majority	34.0	*Deliberate*: Interact frequently with their peers but seldom hold positions of opinion leadership in a social system, may deliberate for sometime before completely adopting an innovation.
Late majority	34.0	*Skeptical*: Adopt innovations just after the average member of the social system has, adopting may be both an economic necessity and a result of increasing peer pressure.
Laggards	16	*Traditional*: Tend to be suspicious of innovations and change agents, poses almost no opinion leadership, many are near isolates in the social network of their system.

[a] The criterion for adopter categorization is innovativeness – defined as the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of the social system.

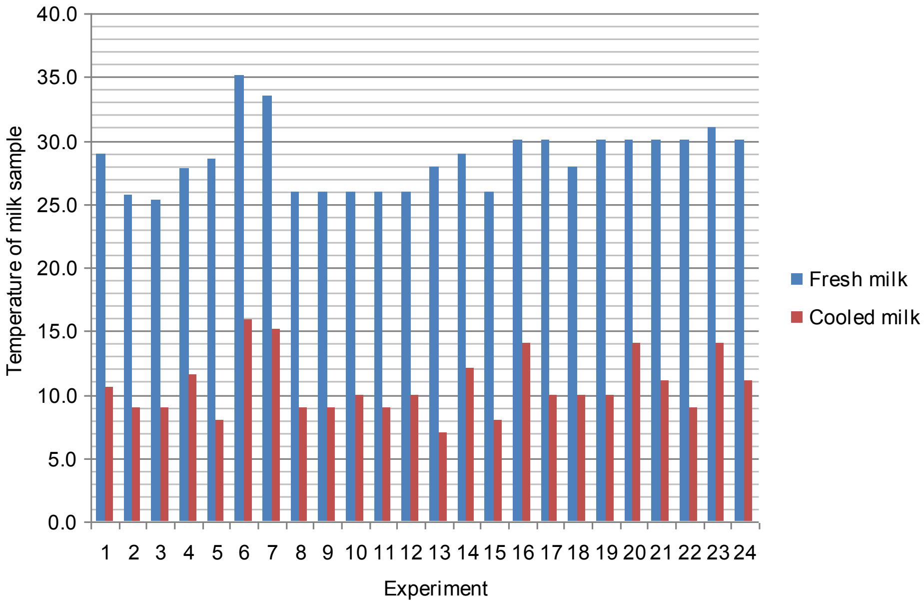

Fig. 6. Temperature of milk samples before and after cooling for 24 h in the evaporative cooler.

and successful diffusion of a larger capacity cooler among early adopters. Second, successful on-farm regeneration of both the large and low-capacity coolers with biogas. By diffusing larger capacity coolers, the diffusion of the small coolers will fast follow. The larger capacity coolers will target well educated, wealthier farmers, who are role models in rural dairy community. The 50–100 L is currently being tested. By regenerating on the farm, the small low capacity cooler weight and transportation problem will be eliminated. Cooled milk will just be transferred to insulated milk cans that are currently used to transport uncooled milk. The diffusion of biogas digesters using cow-dung as a substrate, for lighting and cooking, from a purely deforestation–prevention angle has frustrated many development agencies and governments in sub-Saharan Africa. A possible explanation is that the cost of cooking with woody biomass has been and is till perceived to be low in comparison to the investment needed for installing a domestic biogas plant. Even when government policies are put in place to change behavior, lack of enforcement and/or corruption have more often than not defeated the purpose. Additionally, cooking and lighting applications do not directly generate cash incomes, making it impossible for farmers to qualify for microcredit loans, given the typical income of the smallholders (less than 5 dollars a day); it is easy to understand why the capital investment into domestic biogas plant for only cooking and lighting has been out of reach. The idea of cooling milk with biogas is likely to be a "killer application", because the extra income generated by the evening milk is expected to make microcredit borrowing for biogas plant construction attainable. As such, adding milk cooling to cooking and lighting will make an investment into a biogas plant very attractive and therefore will quickly enable the narrowing of the gap between installed capacity of 600 and potential of 200,000 domestic plants [35]. The latest most comprehensive study [35] found no biogas-powered milk cooling application in Uganda.

Western Uganda was probably not the most ideal location to start, because milk prices are lower in comparison to Districts in Central region, suggesting that the next generation of the cooler should be diffused in a high milk price region. Also, in the end-of-project informal interview, farmers highly recommended establishing a demonstration/training center in the model of a smallholder mixed farm, where they could come to "see to believe" before they could commit to adopting the technology. Such a center could also serve as a provider for other information needed by the farmers.

Currently, the management practice on smallholder farms in Uganda is to pile up the cow dung in a pit till it is ready for application to crops as fertilizer or manure. Although the pits are typically open to the air, the air does not penetrate deep enough, that the cow dung slurry undergoes anaerobic fermentation producing biogas that is emitted in the air. Bubbling pits are a common site on smallholder farms especially the zero-grazing types. Methane is a potent greenhouse gas (GHG) with a global warming potential 23 times that of CO_2 [36]. GHG emissions have been at the forefront as clearly stated in Kyoto Protocol, whose objective was reducing GHG emissions by 2008–2012 [37]. The percentage contribution to greenhouse gases by Ugandan smallholder dairy operations has not been established. Baseline studies similar to that of Yacob et al. [38] are needed.

4. Conclusion

The results from this study, in addition to affirming that at the micro-level, societal shaping of technology is indispensable to successful diffusion, support the following conclusions:

1. The evaporative cooler innovation satisfactorily added the cooled evening milk to the cold chain over a 24 h cooling period, attesting to its efficacy.
2. The distribution of RUKAKA smallholder farmers with respect to innovativeness is similar to the distribution found in other rural communities.

With a cooler innovation performing satisfactorily with respect to adding the milk to the cold chain, the authors are confident that if the steps proposed herein are followed, on-smallholder farm milk cooling will take a firm hold not only in Uganda but in a number of sub-Saharan countries with similarly structured dairy industries.

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