

Effectiveness, Safety, and Sustainability of a Hand Water Pump Among Women Vegetable Farmers in the Gambia

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Women vegetable farmers (n = 48) in West Africa engaged in timed trials with a hand water pump and traditional water lifting methods. Use of the water pump increased the mean time required to lift water by 14% (p < 0.01), compared to traditional lifting. Average and maximum heart rates increased by 7% and 6%, respectively (each p < 0.01), compared to traditional water lifting. Discomfort and injury indicators were consistently better for the pump. Two months later, most subjects reported that the water pump was safer (65%), faster (77%), and was preferred (77%). Manual water pumps should be comprehensively evaluated for efficiency and long-term sustainability.

KEYWORDS hand water pump, Africa, vegetable farming, women, worker health

INTRODUCTION

The sustainability of farming systems in Africa, as in every other continent, is dependent upon the availability of adequate supplies of water. However,

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in Africa, water lifting and movement is particularly arduous due to limited application of appropriate technologies and the effects of climate change (FAO, 2004). Women are typically responsible for collecting water for household use, as well as for irrigating their dry-season vegetable gardens, which requires large volumes of water (Carney, 1998). Women vegetable farmers in our study in The Gambia (West Africa) stated that watering was the most time-consuming and painful task in the garden, requiring an estimated five hours to lift and carry approximately 400 liters of water daily during the dry season (Vanderwal, 2009; Kuye et al., 2006). The water is typically lifted by multiple (~80/day) repetitions of dropping and lifting a bucket (normally 5 to 7 L) tied to a rope into an open well (Vanderwal, 2009), which presents multiple physical risk factors for musculoskeletal discomfort and injuries (Fathallah et al., 2008).

Vegetable production is important in Africa, particularly for women, as they can be raised in a small land area, contain essential nutrients and micronutrients for family consumption, and can also be sold to generate income to alleviate poverty (NAWFA, 2007). However, the difficulty of conveying the large amounts of water needed tends to reduce the amount of crops planted, as well as the volume harvested. The large amount of time required for lifting water also reduces the amount of time the women have for other activities, reducing their social well-being, and also negatively impacts their health and safety (NAWFA, 2007; FAO, 2004). This negative impact on the farmers also reduces the health and sustainability of the entire farming/ food production system.

Technologies used to irrigate crops must be: a) efficient, b) have low environmental and human impact, and c) sustainable in the long-term (FAO, 2004). This improves the sustainability of the entire production system. In the farming system in this study, human-powered water lifting devices are considered to be the most sustainable (FAO, 2004). Numerous types of human-powered water-lifting devices have been introduced in Africa by various organizations, with varying degrees of stakeholder involvement in their selection and evaluation (FAO, 2004). The few evaluation studies of these devices indicate highly variable improvement in water lifting, and very little information about safety and long-term sustainability is available (FAO, 2004). Accordingly, we used a mixed-methods community participatory research approach (Vanderwal, 2009; Creswell et al., 2003) in which subjects agreed to test a hand crank “rope and washer” water pump. This pump is promoted by an international non-governmental organization (NGO) working in The Gambia but is manufactured and maintained locally.

We used quantitative methods to describe worker productivity, discomfort and injury risk, and some indicators of long-term worker acceptance of the intervention. To compliment these data, qualitative individual interviews,

focus groups, and observations were conducted to identify enabling factors and barriers to long-term acceptability of the intervention.

METHODS

Setting

This research was conducted in a vegetable garden outside a small village in The Gambia. A local NGO oversees the garden and willingly cooperated with the research team in implementing this study. More detailed information on this garden and the overall project implementation has been published previously (Vanderwal, 2009).

Subjects

Of the 212 women who each work in their own plot in the garden, 48 were randomly selected to participate. The project team introduced the study and administered informed consent in Mandinka, the local language, as approved by The Gambia Human Ethics Committee (SCC/EC #1123) and the University of Iowa Institutional Review Board (IRB ID# 200808704). All selected women consented to participate in the study. Subjects were provided with a small monetary incentive for their participation, which was not made known to them until the end of the study.

Selection of Intervention to be Evaluated

After consenting, a participatory focus group, observation of women during work, and key informant interviews identified water lifting as an intervention task. Subjects were asked about the various gardening tasks, as well as the pain and challenges of each task. Those tasks that were the most painful, injury-prone, or time-consuming, and were amenable to intervention were selected for the study (Vanderwal, 2009).

Through a second focus group (held one week after the first) and key informant interviews, the water-lifting intervention to be evaluated was agreed. Subjects provided feedback on the various human-powered water pumps presented by the research team and were encouraged to generate ideas of other low-cost interventions to improve water-lifting. Among other ideas, a foot-operated treadle pump was suggested, but subjects said it was “*too hard*” to pump and refused to test it (Vanderwal, 2009).

Subjects agreed to test a hand crank “rope and washer” water pump (Vanderwal, 2009) (Figure 1). Local technicians from the NGO installed two pumps in the garden, at a total cost of approximately US\$300 per pump. Participants were instructed on the proper use of the pump before study measurement began.



FIGURE 1 Subject using the hand water pump.

Data Collection Methods

TIMING OF DATA COLLECTION

Two rounds of water-lifting trials were conducted, one in December 2008 and the second in February 2009 (Table 1). In each round, subjects were randomly assigned to either begin with traditional water lifting or with the hand pump, and alternated between the two methods in subsequent trials, using each method two times. Data were collected after each trial.

Based on the estimated daily water lifting of 400 liters per day, participants lifted 80 liters of water in each of four trials in December and 100 liters per trial in February (Vanderwal, 2009).

In January and March 2009, follow-up focus group discussions were held with twelve different randomly-selected subjects to gain feedback on their perceptions and experiences with the pumps since the initial trials.

TABLE 1 Key Characteristics of Water Lifting Trials

Characteristic	December round	February round
Volume of water lifted (L)	80	100
Depth of wells with pump (M)	3.9 and 4.7	5.8 and 7.8
Depth of wells used for traditional lifting-range (M)	3.7 – 4.7	5.4 – 7.9
Length of time pumps were in garden before testing	2 weeks	10 weeks

Immediately prior to the February round of water-lifting trials, follow-up individual interviews were conducted with all subjects. All subjects not present the day of the February trials ($n = 7$) were interviewed the following week.

DATA COLLECTED IN EACH TRIAL

All data collection instruments were developed in English and translated to Mandinka with extensive input from local research team members. Students from the Gambia College School of Public Health were extensively trained to conduct interviews and collect physiological data.

Subject biographical data, including height, weight, and age, were collected through individual interviews at the beginning of the study. After the subjects lifted the required volume of water in each trial, interviewers recorded the length of time required, as well as the subject's average and maximum heart rate, using a heart rate monitor with chest strap (Reebok Precision Trainer XT). Subjects then reported their level of comfort or discomfort (on a 5-point scale) in each of four body regions (neck/shoulders, arms, lower back, legs), as well as any injuries or injury near misses in that trial.

The interviewers observed the subjects throughout each trial to monitor their working conditions and measured the depth of the well used in each trial. Interviewers also recorded subjects' qualitative feedback on the water-lifting methods used.

FOLLOW-UP DATA COLLECTED

In the follow-up focus groups, subjects reported their perceptions of the water pump, any injuries or near misses incurred in water lifting since the initial trials, and the reaction of others to the pump. In the two-month follow-up individual interviews, each subject was asked questions with a range of pre-determined answers on their use of the pump, where their plot is located from the pump, any injuries or near misses since the initial trials, and their thoughts on which water-lifting method was safer, easier, faster, and which

they preferred. Subjects were also encouraged to provide qualitative feedback on the reasons for their preferences and any suggestions to improve the pumps.

The Principal Investigator (PI) also observed the subjects 15 times (~weekly), for at least 2 hours per observation, from October 2008 to March 2009, using an open-ended form to document observed activities and behaviors.

Data Analysis

STATISTICAL ANALYSIS OF QUANTITATIVE DATA

Mean times for water lifting, average heart rates, and maximum heart rates were compared for each water lifting method in repeated trials using Generalized Estimating Equations (GEE) (Zeger & Liang, 1986; SAS, 2008).

Independent variables that were significant ($p < 0.05$) for at least one outcome or were significant covariates in previous studies were included in multivariable modeling for all three continuous outcomes. These included: well depth, month of trial, and subject height and age.

Discomfort and injury near miss results from the trials were dichotomized and then water lifting methods were compared through odds ratios calculated using GEE models. For the dichotomized outcomes, the independent variables used in multivariable modeling included: subject height and age, well depth, the interaction term of height*method, and subject weight (for two outcomes).

Subject identification number was used as the clustering factor to enable repeated comparisons of the same subject using either the water pump or the traditional method, which was the primary independent variable of interest. GEE analyses were performed using PROC GENMOD in SAS Version 9.2 (SAS, 2009).

The number of injuries and near misses occurring during the follow-up period were compared for each water lifting method using chi-square and Fisher's exact tests.

Each outcome response in the two-month follow-up individual interviews was compared to each independent variable using logistic regression analysis to identify any factors predictive for outcome responses.

ANALYSIS OF QUALITATIVE DATA

All information gathered through qualitative data collection methods (focus groups, observation, and individual interviews) was analyzed to identify common themes, explaining subjects' attitudes and behavior regarding the pump (Glaser & Strauss, 1967). All opinions expressed by subjects were analyzed, with particular attention given to the number of subjects reporting specific points.

RESULTS

Subjects

All 48 enrolled subjects participated in the December trials, while some ($n = 7$) were not present the day of the February trials (Table 2), due to family commitments. Some subjects requested to not complete their second trial with the pump or with both the pump and traditional lifting (Table 2). These subjects reported that they were very tired from the previous trials or were generally fatigued that day. The demographics of those subjects that did not complete all 4 trials were generally the same as those of all subjects (Table 3).

Length and Effort of Water Lifting Trials

Subjects took an average of 276 seconds to lift water using the pump, 13% (95% CI = 5.2–20.1%) more than the 242 seconds for the traditional method (Table 4). The difference between methods within shorter subjects

TABLE 2 Subject Participation in the Trials

Variable	December round	February round
Number of subjects in trial round	48	41
Number of trials conducted	188	149
Subjects NOT completing second trial with pump	0	7
Subjects NOT completing second trial with pump AND traditional method	2	4

TABLE 3 Characteristics of All Subjects ($n = 48$)

Characteristic	Mean (SD)	N (%)
Height (m)	1.60 (0.06)	N/A
Weight (kg)	58.7 (10.5)	N/A
Age range		
18–39 years	N/A	10 (21%)
40–49 years	N/A	10 (21%)
50–59 years	N/A	10 (21%)
60–89 years	N/A	16 (33%)*
Don't know	N/A	2 (4%)
Years garden experience		
<10 years	N/A	16 (34%)
11–20 years	N/A	12 (25%)
>20 years	N/A	19 (40%)
Don't know	N/A	2 (4%)

*Note that only two subjects were older than 70 years.

sd = standard deviation.

N = number of subjects.

(< 1.62 m) was significant ($p < 0.01$), but within taller subjects (≥ 1.62 m), the methods were not significantly different ($p = 0.49$).

Subject average and maximum heart rates were 7% and 6% higher ($p < 0.01$), respectively, when using the water pump than the traditional method (Table 4), with similar results within both height categories. Multivariable adjustment for the factors of well depth, month of trial, and subject height and age changed the estimated differences between methods very little.

Discomfort and Injuries

Use of the water pump significantly reduced the odds of subjects reporting discomfort in the lower back during the trials (Table 5). The water pump also reduced the odds of discomfort in all other body regions, as well as injury near misses, but differences were not significant. After multivariable adjustment, the odds of reporting discomfort in the neck and shoulders, lower back, and hips and legs were all significantly less with the water pump.

The month of the trial, time required for the trial, and average and maximum heart rates were not significant predictors of discomfort in any body region in univariate analysis. The consecutive trial number (1, 2, 3, or 4) was also not a significant predictor of any outcome in this study, indicating no effect of a “learning curve” or fatigue when proceeding from the first to the last trial.

Injuries were reported in two of the 337 water lifting trials, both when using the traditional method (abrasion on knee and cut on thumb). Near misses were reported in 22 of the 173 trials with the traditional method, while only 13 near misses were reported in the 164 trials with the pump (Table 5),

TABLE 4 Mean Values of Continuous Outcomes by Method Used and % Difference from Traditional Method

Variable	All subjects			Height < 1.62 m		Height \geq 1.62 m	
	Mean values		Adjusted* % difference (95% CI)	Mean values		Mean values	
	Pump (n = 164)	Traditional (n = 173)		Pump (n = 103)	Traditional (n = 108)	Pump (n = 61)	Traditional (n = 65)
Time required (seconds)	275.6	241.9	+13 (5.2–20.1)	297.7 [†]	250.8	236.2	227.0
Average Heart Rate (bpm)	132.4	124.4	+7 (4.1–8.8)	133.6 [†]	124.9	130.7 [†]	123.8
Maximum Heart Rate (bpm)	144.5	136.1	+6 (3.2–9.4)	144.3 [†]	136.5	144.6 [†]	135.6

bpm = beats per minute.

*Values were adjusted for well depth, month of trial, and subject height and age, through a multivariate linear model.

[†]Value is significantly ($p < 0.05$) different than subjects in the same height category using the traditional method.

TABLE 5 Association of Water Lifting Method with Discomfort and Injury Outcomes in the Trials

Outcome	Intervention method	N	% discomfort**	Unadjusted values			Adjusted* values		
				Odds ratio	Lower CL	Upper CL	Odds ratio	Lower CL	Upper CL
Neck and shoulder discomfort	Water pump	164	40%	0.56	0.31	1.04	0.30	0.10	0.89
	Traditional	173	54%	–	–	–	–	–	–
Arm and hand discomfort	Water pump	164	37%	0.60	0.33	1.10	0.38	0.12	1.24
	Traditional	173	50%	–	–	–	–	–	–
Lower back discomfort†	Water pump	164	27%	0.38	0.21	0.68	0.15	0.06	0.34
	Traditional	173	49%	–	–	–	–	–	–
Hip and leg discomfort†	Water pump	164	27%	0.61	0.37	1.02	0.30	0.12	0.80
	Traditional	173	38%	–	–	–	–	–	–
Injury near miss‡	Water pump	164	8%	0.59	0.30	1.16	0.56	0.31	1.04
	Traditional	173	13%	–	–	–	–	–	–

CL = Confidence limit.

*All values were adjusted for subject height, age, well depth, and interaction term of height*method.

†In addition, outcomes were also adjusted for weight.

‡Adjusted for subject height and age only.

**Indicates the % of trials for that method where subjects reported discomfort. For the injury near miss outcome, indicates the % of trials reporting an injury near miss.

although the difference between methods was not significant (chi-square test $p = 0.15$).

No injuries were reported with either the water pump or traditional method in the two months after the initial trials. Three (3) subjects reported an injury near miss when using the traditional method in the follow-up period, compared with no near misses reported with the pump, but the difference was not significant (Fisher's exact test $p = 0.24$).

Acceptability of the Water Pump

When asked immediately after each trial which method they thought was safer, 72% of subjects said the pump was either “definitely” or “probably” safer, 10% said the traditional method was safer, and 17% said both methods were the same. Seventy-two percent (72%) of subjects said the pump was easier to use, while 22% said the traditional method was easier, and 6% said both were the same.

When combining the responses of “definitely the pump” and “probably the pump” (Table 6), most subjects indicated in the two-month follow-up interviews that they felt the water pump was safer (65%), easier (63%), faster (77%), and was preferred (77%).

TABLE 6 Comparison of Subject Perception of Pump to Traditional Water Lifting Methods, Two Months After the Initial Trials

Rating	Frequency of persons reporting					Total
	Definitely traditional	Probably traditional	Both the same	Probably pump	Definitely pump	
Safer	3 (6%)	5 (10%)	9 (19%)	8 (17%)	23 (48%)	48
Easier	9 (19%)	5 (10%)	4 (8%)	10 (21%)	20 (42%)	48
Faster	5 (10%)	4 (8%)	2 (4%)	14 (29%)	23 (48%)	48
Prefer	7 (15%)	2 (4%)	2 (4%)	9 (19%)	28 (58%)	48
Total	24 (13%)	16 (8%)	17 (9%)	41 (21%)	94 (49%)	192

The percentages listed immediately after the frequency counts are expressed as the % of the total for that row.

However, two months after the initial trials, 44% of subjects reported not using the water pump at all since the initial trials, 10 of 48 subjects reported that they used the pump 25% of their time, while only 11 subjects reported using it 75% or more of their time in water lifting. When given three pre-determined response options, only 10% of subjects reported that a pump was “at the well I normally use,” with 19% stating the pump was “next to the well I normally use,” and 71% saying the pumps were “far from the well I normally use.”

The factor most significantly associated with any follow-up response in univariate analysis was pump location (at or near well normally used vs. pump far from normal well), which was predictive ($p < 0.01$) for increasing the amount of time subjects reported using the pump. Taller subject height (≥ 1.62 meters; $p = 0.06$) and fewer years of garden experience (< 10 years experience; $p = 0.10$) also tended to increase reported pump use.

From the qualitative data, we identified various enabling factors and barriers to long-term sustainability of the pump, summarized in Table 7 and further explained by Vanderwal (2009).

DISCUSSION

Numerous factors contribute to subjects' acceptability of an intervention, all of which must be considered when developing, implementing, and promoting interventions (Fathallah et al., 2008; FAO, 1998). Although the pump required more time and effort in the trials than the traditional method, the pump was preferred by most subjects.

The improved comfort and safety of using the pump was a major reason for its acceptance. In all the trial and follow-up data, the pump reduced both general and localized body pain and fatigue, as well as the likelihood of injury. Subjects also felt the pumps were safer for children to use, as they often help with water-lifting.

TABLE 7 Summary of Themes in Qualitative Findings

Enabling factors	Barriers
– Improved safety	– Force required to turn the pump
– Perceived increased productivity	– Height of pump handle
– Less discomfort when using	– Unavailability of pumps
– Novelty	– Lack of familiarity
– Unexpected events less likely	– Inefficiency of pumping
– Approval of men and other villagers	– Pump malfunctioning

Perceived work productivity also strongly impacts an intervention's acceptability (FAO, 1998; Aubel & Samba-Ndure, 1996). Subjects were not informed of the trial results until the completion of the entire study. Therefore, subjects formed their own perceptions, with 77% indicating in follow-up interviews that they felt the pump was faster than the traditional method despite measurements that indicated otherwise.

Other people's opinions about the pump also impact acceptability and long-term sustainability (FAO, 1998; Kaul, 1993). Subjects stated that their neighbors wanted similar pumps and that their husbands had no objections to the pumps, both views lending to increased desirability of the pump. This is particularly important in African society, as male disapproval of certain water pumps has caused women not to use the available technology in other studies (FAO, 1998; Kaul, 1993).

Despite the general acceptance of the pump, we identified a number of barriers that likely decreased the productivity and use of the pump, which were well received by the NGO promoting the pump. The pump's design caused its handle to be "heavy to turn." For many subjects, this was because the handle was too high for them. On average, the pump handles were 1.63 m above the ground at their highest point, while subject median height was 1.60 m. Therefore, > 50% of subjects needed to reach above their head to pump. This was evident in the trials, where the shorter subjects required more time and effort to use the pump than the taller subjects (Table 4). The pump NGO reported that they will reduce the radius of the pump handle and will make a raised concrete platform where women can stand to use the pump, thus incorporating anthropometrics in its design (FAO, 1998; Egharevba & Iweze, 2004).

The pump's design also reduced the efficiency of pumping, as it allowed the water to seep down the intake pipe after the cranking stopped. The pump NGO is exploring other pump designs that would hold the water in the intake pipe for the next use. A large reservoir (≥ 100 liters) could also be placed at the outlet of the pump, so that subjects could pump water continuously to fill the reservoir, without stopping to re-position the receiving buckets.

Resistance to change is another important barrier to intervention adoption (Rogers, 2003). Some subjects prefer to continue in a familiar method, regardless of its utility. More years of garden experience decreased reported use of the pumps and increasing subject age also reduced the pump's acceptance in qualitative findings, indicating that older subjects may be more resistant to change.

Another important factor decreasing use of the pump was that pumps were only installed on two of the 22 wells in the garden. Accordingly, many subjects would need to carry water lifted with a pump a great distance to their plot, so they continued with their traditional method. However, the PI noted various times on arrival in the garden that women were using the traditional method at the same well as there was a functioning and available pump, indicating that the other listed barriers were also very important.

One limitation of this study is that subjects were more accustomed to the traditional method, so it seemed to be easier for them to "race" in the timed trials with the traditional method. This could be addressed by increasing the amount of water required for lifting. In addition, the pumps would be more advantageous compared with traditional lifting if the wells were deeper ($\sim > 10$ m), as traditional lifting would be even heavier, time consuming and more dangerous.

Although numerous steps were taken to obtain unbiased responses (Vanderwal, 2009; Faucett et al., 2007), it appeared that subjects may have reported they liked the pump to please the study team. This may be addressed by having subjects evaluate two different pump types, as well as the traditional method. Data from only one garden may limit its generalizability; however, the 100% participation rate for the randomly selected subjects improves its generalizability.

CONCLUSIONS

Compared with traditional methods, the water pump improved worker comfort and safety and presented indicators of long-term acceptance and sustainability. However, use of the pump in this study increased the time and effort required to lift water, compared to traditional lifting. Based on this study, a number of improvements are being made to the pump, which should improve its efficiency and usability.

The information on the barriers and enabling factors essential for long-term sustainability could be used by other pump manufacturers and promoters to provide improved water pumps in developing countries, particularly for women vegetable farmers in Africa. This information will be disseminated to NGOs, United Nations agencies, governments, and others involved in introducing water lifting devices throughout Africa.

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REFERENCES

- Aubel, J., & Samba-Ndure, K. 1996. Lessons on sustainability for community health projects. *World Health Forum* 17:52–57.
- Carney, J. 1998. Women's land rights in Gambian irrigated rice schemes: constraints and opportunities. *Agriculture and Human Values* 15:325–336.
- Creswell, J., Plano Clark, V., Gutmann, M., Hanson, W. 2003. Advanced mixed methods research designs. In: *Handbook of mixed methods in social and behavioral research*, A. Tashakkori, C. Teddlie (eds.) pp. 209–240. Thousand Oaks, California: Sage.
- Egharevba, R., & Iweze, F. 2004. Sustainable agriculture and rural women: Crop production and accompanied health hazards on women farmers in six rural communities in Edo State Nigeria. *Journal of Sustainable Agriculture* 2004;24:39–51.
- Fathallah, F. A., Miller, B. J., Miles, J.A. 2008. Low back disorders in agriculture and the role of stooped work: Scope, potential interventions, and research needs. *Journal of Agricultural, Safety and Health* 14:221–245.
- Faucett, J., Meyers, J., Miles, J., Janowitz, I., Fathallah, F. 2007. Rest break interventions in stoop labor tasks. *Applied Ergonomics* 38:219–226.
- Food and Agriculture Organization of the United Nations (FAO). 2004. *Appropriate water-lifting technologies in West Africa*. Rome: FAO:2004. Available from: <http://www.fao.org/docrep/008/y5891e/y5891e00.HTM> [Accessed on 9 June 2009].
- Food and Agriculture Organization of the United Nations (FAO)/International Fund for Agricultural Development (IFAD). 1998. *Agricultural implements*

- used by women farmers in Africa. Rome: FAO:1998. Available from: <http://www.ifad.org/pub/other/lifadafr.pdf>. [Accessed on 6 Nov 2006].
- Glaser, B., & Strauss, A. 1967. *The discovery of grounded theory: strategies for qualitative research*. Chicago: Adline Publishing Company.
- Kaul, R. 1993. Labour in agricultural production in Asia and Africa and the need for ergonomic interventions. In: *Proceedings of the XXV CIOSTA-CIGR V Congress: farm planning, labour and labour conditions, computers in agricultural management*. Wageningen, the Netherlands: pp. 20–27.
- Kuye, R., Donham, K., Marquez, S., Sanderson, W., Fuortes, L., Rautiainen, R., et al. 2006. Agricultural health in The Gambia I: agricultural practices and developments. *Annals of Agricultural and Environmental Medicine* 13:1–12.
- National Women Farmer's Association of The Gambia (NAWFA). 2007. Five Year Programme Strategy: January 2007–December 2011. Serrekunda, The Gambia:NAWFA.
- Rogers, E. 2003. *Diffusion of innovations*. New York: Free Press.
- SAS Institute Inc. 2008. *General estimating equations*. Cary, NC:SAS. Available from: <http://support.sas.com/rnd/app/da/new/dagee.html> [Accessed on 10 January 2010].
- SAS Institute Inc. 2009. *The GENMOD procedure*. Cary, NC:SAS. Available from: http://support.sas.com/documentation/cdl/en/statug/63033/HTML/default/genmod_toc.htm [Accessed 10 January 2010].
- Vanderwal, L.S. 2009. Improving the health, safety, and productivity of women vegetable farmers in The Gambia [dissertation]. Iowa City, Iowa: University of Iowa.
- Zeger, S., & Liang, K. 1986. The analysis of discrete and continuous longitudinal data. *Biometrics* 42:121–130.